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Editorial office: Křižíkova 384/101 Karlín, 186 00 Praha

E-mail: info@european-science.org
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ECONOMIC SCIENCES

FINANCIAL MECHANISMS FOR STIMULATING GREEN INVESTMENT: ANALYTICAL ASSESSMENT AND DEVELOPMENT PROSPECTS IN UKRAINE

Korol S.
Ph.D. in Economics, Associate Professor of the Department of Finance, Accounting and Taxation
Karmanskyi A.
PhD Student,
Ivano-Frankivsk National Technical University of Oil and Gas, Ukraine
DOI: 10.5281/zenodo.21364042

ABSTRACT

The article examines the financial instruments of "green" investment in Ukraine during 2020-2024 under conditions of multiple crises − the pandemic, full-scale war, and European integration processes. The essence and classification of the main instruments are revealed, including green bonds, green lending, grants, the green tariff and the auction mechanism for supporting renewable energy, as well as tax incentives. A comprehensive analysis of the dynamics of green finance indicators is conducted, and key trends in the development of the institutional and financial ecosystem are identified. Particular attention is paid to the role of international financial organizations (IMF, IFC, EBRD) and donor programs in stimulating green investment. The effectiveness of each instrument is assessed through the lens of the environmental, social, and economic results achieved. Prospects for implementing EU standards in sustainable finance, adapting the taxonomy, and ESG reporting are substantiated. Recommendations are formulated for modernizing the regulatory framework, strengthening institutional coordination, and developing the market for green financial products to ensure the systemic environmental transformation of Ukraine's economy.

Keywords: green investment, green bonds, ESG, sustainable development, green lending, EU taxonomy, renewable energy, green tariff, IMF, environmental transformation.

Introduction. In the context of the global transition to a low-carbon economy, green investment is acquiring strategic importance as a key instrument for ensuring sustainable development, energy security, and social resilience. For Ukraine, which during 2020-2024 faced the COVID-19 pandemic, full-scale armed aggression, and active European integration processes, the formation of effective green finance mechanisms became not only an environmental priority but also a strategic necessity for preserving competitiveness and attracting international capital.

The relevance of the study is determined by several interrelated factors. First, the Association Agreement between Ukraine and the EU envisages the gradual harmonization of environmental and financial standards, making the implementation of green finance instruments a mandatory condition for access to the Union's markets and funds. Second, Ukraine's Green Recovery Plan (DREAM), approved in 2022, orients all public investment projects toward compliance with the six environmental objectives of the EU Taxonomy. Third, international partners − the IMF, the World Bank, the EBRD, and the IFC − link the provision of financial support to progress in implementing environmental reforms.

Despite the considerable body of scholarly work in the field of green finance − the studies of Dyma V.V. [18], Dyba M.I. and Hernego Yu.O. [17], Karnaushenko A.S. [19], Khakhaliev D.Yu. and Nemashkalo K.O. [40], Frolov A. [39], and foreign authors − a systematic analysis of the effectiveness of specific financial instruments under martial law and post-conflict recovery remains outside the scope of researchers' attention. This defines the purpose and objectives of this article.

The purpose of the article is to conduct a comprehensive analysis of the financial instruments of "green" investment in Ukraine during 2020-2024, to assess their effectiveness, and to identify prospects for their further application in the context of European integration and post-conflict recovery.

To achieve this purpose, the following objectives are set: to systematize the classification of financial instruments of green investment; to analyze the dynamics of key indicators for 2020-2024; to assess the effectiveness of each instrument through the lens of the results achieved; to determine the role of international institutions; and to substantiate the prospects for the development of green finance in the context of European integration. The methodological basis of the study comprises methods of systemic analysis, statistical comparison, structural-logical modeling, and generalization.

Materials and methods of research. The material basis of the study comprises statistical data from the National Bank of Ukraine, the Ministry of Finance of Ukraine, the Ministry of Economy, Environment and Agriculture of Ukraine, the State Statistics Service of Ukraine, as well as analytical reports of international financial organizations − the IMF, the World Bank, the EBRD, the IFC, KfW, and the Green Climate Fund. Regulatory documents of the European Union were used, in particular the EU Taxonomy and ESG reporting standards that define the criteria for sustainable finance. An additional source comprised scholarly publications by Ukrainian and foreign authors analyzing the development of green investment and its institutional mechanisms.

The methodological basis of the study includes systemic analysis to identify the interrelationships between financial instruments and the institutional environment, statistical comparison to assess the dynamics of green finance indicators in 2020-2024, and structural-logical modeling to construct a classification of instruments and determine their effectiveness. Case analysis of practical examples of the use of green bonds, loans, grants, and tariff and tax incentives was applied. The generalization of results made it possible to formulate recommendations for modernizing the regulatory framework and developing the market for green financial products.

A distinctive feature of the methodology is the combination of quantitative and qualitative approaches. The study period covers 2020-2024, which ensures that the impact of the COVID-19 pandemic, martial law, and European integration processes is taken into account. The effectiveness of financial instruments was assessed through the lens of environmental, social, and economic outcomes in accordance with ESG principles. To ensure the reliability of the data, cross-verification of indicators from several independent sources was applied.

Thus, the materials and methods used made it possible to conduct a comprehensive analysis of the financial mechanisms for stimulating green investment and to identify the prospects for their development in Ukraine under conditions of post-conflict recovery and European integration.

Research results. "Green" investments are capital investments in projects and assets that promote sustainable development, reduce the negative impact on the environment, and facilitate the transition to a low-carbon economy [1]. Unlike traditional investments, they are assessed not only by financial indicators but also by environmental, social, and governance criteria (ESG − Environmental, Social, Governance).

The scholarly literature identifies several theoretical approaches to understanding green investment. The first − the instrumental approach − regards green investment primarily as a mechanism for reallocating capital from "dirty" to "green" sectors [17]. The second − the systemic approach − emphasizes the need to form a holistic institutional and financial ecosystem that combines the regulatory environment, financial markets, and social values [20]. The third − the transformational approach − highlights the role of green finance as a catalyst for the structural restructuring of the economy toward sustainable development [1].

According to the classification of the Razumkov Centre [20] and the analytical report of DiXi Group [1], the main financial instruments of green investment are divided into five groups: debt instruments (green bonds, green loans); equity instruments (shares of ESG companies, green funds); subsidy instruments (grants, tax benefits, tariff support); guarantee instruments (state and international guarantees); and mixed instruments (combined products). In the Ukrainian context, the first three groups achieved the greatest development during the period analyzed.

It is fundamentally important to have a verification system that confirms the "green" nature of investments. According to the EU Taxonomy [3], a financial instrument may be considered "green" if it substantially contributes to at least one of six environmental objectives: climate change mitigation; climate change adaptation; the protection of water resources; the transition to a circular economy; pollution prevention; and the protection of biodiversity − while not causing significant harm to other objectives (the DNSH principle − Do No Significant Harm). The implementation of these principles in Ukraine began within the framework of the DREAM Green Recovery Plan [2].

We therefore begin the analysis of the key financial instruments of green investment in Ukraine with green bonds. Green bonds are debt securities whose proceeds are directed exclusively toward financing environmentally sustainable projects [14]. In Ukraine, the first issues were carried out by Ukrgasbank in partnership with the IFC, which marked the starting point for the formation of the green debt finance market. The instrument facilitates the attraction of long-term capital for projects in renewable energy (RES), energy efficiency, water treatment, and environmental transport. The green bond market demonstrates steady growth, rising from UAH 1,2 billion (3 issuers) in 2021 to UAH 7,1 billion (9 issuers) in 2024 − a sixfold increase over four years (Table 1). The effectiveness of the instrument is determined by the transparency of verification and the trust of institutional investors [19].

Table 1

Volume of green bond issuance in Ukraine, 2020-2024

Year	Issuance volume, UAH billion	Number of issuers	Main areas of financing
2020	–	–	–
2021	1,2	3	Energy efficiency, RES
2022	2,8	5	Biogas, water treatment
2023	4,5	7	Transport, construction
2024	7,1	9	RES, logistics, environmental infrastructure

Note: compiled by the authors based on data from [14; 19]

The next instrument is green loans − bank loans granted for the implementation of environmentally oriented projects [6]. The leading players are Ukrgasbank, Oschadbank, and Ukreximbank, operating in partnership with the IFC, EBRD, and KfW. The growth dynamics are impressive, with an almost ninefold increase in volume, from UAH 1,1 billion (34 projects) in 2020 to UAH 9,3 billion (194 projects) in 2024 (Table 2). The reduction of the average payback period from 4,2 to 3,2 years indicates an increase in investment efficiency. The evolution of the financing structure − from basic solutions (solar panels, greenhouses) to complex

infrastructure and municipal projects − points to the formation of a mature green lending ecosystem.

Table 2

Volume of green lending in Ukraine, 2020-2024

Year	Volume, UAH billion	No. of projects	Avg. payback period, years	Main areas
2020	1,1	34	4,2	Solar panels, greenhouses
2021	2,9	76	3,9	Biogas, buildings
2022	5,4	121	3,6	RES, manufacturing
2023	7,8	168	3,4	Transport, logistics
2024	9,3	194	3,2	RES, agro-energy

Note: compiled by the authors based on data from [6; 16; 28; 31; 33; 41]

The next instrument comprises grants and co-financing programs. Grants represent non-repayable financial assistance for the implementation of environmental projects. In Ukraine, grant programs are implemented through USAID, GIZ, the Green Climate Fund (GCF), the EU, and local budgets [26]. During 2020-2024, grant support increased sixfold, rising from 42 projects and UAH 180 million to 243 projects and UAH 1,120 million (Table 3). Overall, grants are an effective instrument for launching innovative projects in communities lacking access to bank financing. The greatest demand is for support of building energy efficiency, water treatment, and environmental education.

Table 3

Volume of grant support for green projects in Ukraine, 2020-2024

Year	Number of projects	Total amount, UAH million	Main donors
2020	42	180	USAID, GIZ
2021	87	390	GCF, EU
2022	134	620	GCF, local budgets
2023	198	840	GCF, USAID, Horizon Europe
2024	243	1120	GCF, EU, Ministry of Economy

Note: compiled by the authors based on open sources and data from [26]

The next instrument is the green tariff and the auction model for supporting RES. The green tariff − a fixed purchase price for electricity from renewable sources − was in effect until 2023 and ensured the initial development of the RES market. Over time, however, the instrument became financially burdensome for the state: the total purchase volume rose from UAH 18,2 billion (UAH 4,32/kWh) in 2020 to UAH 26,1 billion (UAH 3,62/kWh) in 2023 (Table 4). The introduction of the auction model in 2024 made it possible to reduce the average price to UAH 2,97/kWh − 18% below the green tariff level [13] − confirming the maturity of the market and the increased efficiency of resource allocation.

Table 4

Volume of RES support, 2020-2024

Year	Purchase volume, UAH billion	Average price, UAH/kWh	Auction price (2024)
2020	18,2	4,32	–
2021	21,5	4,10	–
2022	24,7	3,85	–
2023	26,1	3,62	–
2024	–	–	2.97

Note: compiled by the authors based on open sources and data from [43]

Among the instruments are tax incentives, which include exemption from import duties on RES equipment; reduced VAT rates; accelerated depreciation for energy-efficient facilities; and tax credits for enterprises implementing environmental standards. They are regulated by the Tax Code of Ukraine [32], resolutions of the Cabinet of Ministers, and sectoral programs of the Ministry of Finance [30]. The number of beneficiary enterprises increased ninefold, rising from 420 to 3820 (Table 5). The total amount of funds saved in 2024 reached UAH 1230 million. The greatest effect is observed in the agro-energy, logistics, and construction sectors, where the incentives reduced project launch costs by 12-18% [12; 30; 32].

Table 5

Volume of tax incentive use for green projects, 2020-2024

Year	Number of enterprises	Funds saved, UAH million	Main types of incentives
2020	420	180	Duty exemption, VAT on equipment
2021	870	410	Accelerated depreciation, credits
2022	1320	690	Incentives for RES, buildings
2023	2460	1050	Incentives for agro-energy
2024	3820	1230	Comprehensive tax packages

Note: compiled by the authors based on open sources and data from [12; 30; 32]

Over the period studied, the total volume of green investment increased almost fivefold, rising from UAH 3,2 billion (48 projects) in 2020 to UAH 15,1 billion (221 projects) in 2024 (Table 6). The greatest growth was observed in 2023-2024, when Ukraine intensified cooperation with the Green Climate Fund and introduced ESG verification mechanisms.

Table 6

Performance indicators of green finance in Ukraine, 2020-2024

Year	Green investment volume, UAH billion	Number of projects	Main instruments
2020	3,2	48	Grants, green tariff
2021	6,5	112	Green loans, bonds
2022	9,8	157	Loans, local programs
2023	12,4	193	Bonds, grants
2024	15,1	221	Bonds, green loans, GCF

Note: compiled by the authors based on data from [8; 18; 27; 39; 40; 42]

IMF programs played a key role in shaping favorable conditions for green finance. The 2020 Stand-By Arrangement ($5 billion) stabilized the exchange rate and replenished the NBU's reserves, reducing risks for investors. The Extended Fund Facility (EFF, $15,6 billion), approved in March 2023, included structural benchmarks for ESG integration into financial policy. The successful completion of five consecutive reviews in 2024 served as a signal of confidence to international donors and a condition for receiving additional support [7; 21; 24].

The coordination of IMF programs with other initiatives − the EU's Ukraine Facility worth EUR 50 billion (2024-2027), and financing from the EBRD, IFC, and KfW − created a synergistic effect. The NBU, through its Sustainable Finance Development Policy until 2025 [33], and Ukrgasbank, through its partner green credit lines [31], ensured the transmission of international support to end beneficiaries.

The environmental effectiveness of the instruments is confirmed by the results achieved, including a reduction in CO_2 emissions of more than 1.2 million tonnes annually in the RES sector; a 30-50% reduction in energy consumption in modernized buildings; a 40% reduction in waste volumes within the circular economy (locally); improved drinking water quality in a number of regions; and the restoration of forest ecosystems and the formation of natural corridors [22; 38]. These results correspond to the six environmental objectives of the EU Taxonomy and confirm the practical effectiveness of green finance.

An analysis of the structure of green investment by the country of origin of international companies (2020-2024) shows the leadership of Germany (33,2% − Knauf, BASF), France (24% − Saint-Gobain), Denmark (16,4% − Rockwool), Poland, and Austria. The total volume of investment by leading foreign companies amounted to UAH 11,13 billion, confirming Ukraine's active integration into global "green" economy value chains and the growing trust of foreign investors [5; 12; 28; 31].

Despite considerable progress, the development of "green" finance in Ukraine is constrained by a number of systemic problems. The first is regulatory uncertainty, as current legislation does not contain an agreed definition of the concept of "green investment," and the implementation of the European taxonomy is fragmented. This complicates the application of environmental criteria in public procurement and budget planning [1; 20].

The second problem is the weakness of institutional coordination. The absence of a single body responsible for the strategic management of green finance leads to duplication of functions among ministries, banks, and local administrations. The third problem comprises financial barriers, as the share of green instruments in banks' portfolios remains low, and the private sector demonstrates caution due to the absence of guarantees and the underdevelopment of green insurance. The fourth is the absence of a centralized platform for monitoring and assessing the effectiveness of green investment, which reduces transparency and complicates reporting.

The prospects for the development of green finance in Ukraine are considerable and are determined by several factors. First, the course toward European integration requires the full implementation of the EU Taxonomy, which will serve as an incentive for the standardization of green instruments. Second, post-conflict recovery, according to World Bank estimates, will require more than USD 400 billion in investment, a significant share of which is oriented toward the principles of green construction and sustainable development. Third, the EU's Ukraine Facility (EUR 50 billion, 2024-2027) ties support to the implementation of environmental standards.

An important direction is the development of the green bond market. According to estimates by the UNDP [14] and analysts at EcoPolityka [34], the potential market volume could reach UAH 50-70 billion by 2030, provided that framework legislation is adopted and independent verification under Climate Bonds Initiative (CBI) standards is introduced. Municipal green bonds for financing local projects, including the reconstruction of schools, hospitals, and water supply systems, are also promising. The pilot experience of Lviv, Ternopil, and Dnipro has demonstrated the effectiveness of this mechanism in combination with USAID and EU programs.

Among the promising innovations, the following should be highlighted: the development of "green" insurance products to hedge the risks of environmental projects; the introduction of climate derivatives and carbon credits; the formation of a "green" startup ecosystem through venture financing (Greencubator, GCIP Ukraine); the development of peer-to-peer green lending platforms for small businesses and farming households; and the introduction of ESG ratings for enterprises to improve access to green finance.

Based on the analysis conducted, a set of recommendations has therefore been formulated for various levels of governance with the aim of ensuring the systemic development of green finance in Ukraine.

At the state level, it is necessary to: adopt a Law of Ukraine "On Green Investment" with clear definitions, classification criteria, and verification mechanisms; develop a National Taxonomy of Green Activities aligned with the EU Taxonomy; create a Unified Digital Platform for the registration, monitoring, and reporting of green projects; introduce mandatory ESG reporting for state-sector enterprises; and establish a Green Guarantee Fund to attract private capital [15; 33].

At the level of the NBU and the financial regulator: incorporate climate risks into prudential requirements for banks (in accordance with NGFS − Network for Greening the Financial System − recommendations); introduce a "green" coefficient to improve capital requirements for green loans; develop ESG reporting standards for the banking sector and mechanisms for their independent verification; and support the development of the green bond market through regulatory incentives [15].

At the level of local self-government: introduce municipal green bonds; develop partnerships with donors (USAID, GCF, KfW) to attract grant and concessional credit financing; implement "green" criteria in public procurement; and form local "green" budgets with a separate expenditure line for environmental projects. These measures will ensure the decentralization of green finance and promote the engagement of civil society.

Conclusion. The analysis conducted has shown that during 2020-2024 a multi-level system of green finance was formed in Ukraine, encompassing five main groups of instruments: green bonds, green loans, grants, tariff support for RES (with a transition to the auction model), and tax incentives. The total volume of green investment increased from UAH 3,2 billion to UAH 15,1 billion (+372%), and the number of projects implemented rose from 48 to 221, indicating qualitative structural changes in the country's investment landscape.

The key success factors were: IMF programs (SBA and EFF), which ensured macroeconomic stability; the active participation of the IFC, EBRD, and KfW in forming green credit lines; the growth of grant financing from the GCF, USAID, and the EU; and the NBU's sustainable finance policy. The environmental results achieved − a reduction of CO_2 emissions by 1,2 million tonnes annually, a 30-50% reduction in energy consumption, and improved water resource quality − confirm the practical effectiveness of the system.

Systemic barriers were identified, including regulatory uncertainty, weak institutional coordination, the absence of centralized monitoring, and limited access of small and medium-sized businesses to green financial products. Overcoming them requires the adoption of a basic law on green investment, the development of a national taxonomy, the introduction of prudential incentives for banks, and the development of a unified digital monitoring platform.

The prospects for the development of green finance are determined primarily by Ukraine's course toward European integration, the scale of post-conflict recovery, and the growing role of international partners. The implementation of the proposed recommendations at the state, regulatory, and municipal levels will make it possible to transform green investment from an isolated phenomenon into a systemic driver of sustainable development and the enhancement of the national economy's competitiveness in the context of European integration.

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EMPRICAL ASSESSING THE MACROECONOMIC AND DEMOGRAPHIC DETERMINANTS OF UNEMPLOYMENT ACROSS EU MEMBER STATES

Taghizada A.
Khazar University
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ABSTRACT

This paper explores the relationship between unemployment and several macroeconomic and demographic factors, including inflation, immigration, educational attainment, GDP per capita, and regional characteristics, using data from all 27 EU member states over the 2021–2023 period. Separate multiple linear regression models were estimated for each year in order to account for differences in economic conditions observed throughout the post-pandemic recovery. The empirical estimates show that higher GDP per capita and educational attainment are generally linked with lower unemployment, whereas the effects of inflation and immigration differ across the examined years. Regional differences also appear to account for part of the variation in unemployment observed among EU member states. The results demonstrate that unemployment in the European Union is influenced by both macroeconomic and structural factors. This evidence may assist policymakers in developing labour market measures that better reflect the economic and structural differences between EU countries.

Keywords: Unemployment, European Union, Inflation, Immigration, Education.

Introduction

Although many economies have experienced considerable economic growth over recent decades, unemployment remains a persistent challenge as a result of its impact on production, household income, and social welfare. Persistent unemployment generates significant inefficiencies and long-term social costs, making the identification of its determinants a central issue in economic research and policymaking (Arestis & Mariscal, 2019).

Unemployment also remains an important issue within the European Union despite decades of economic integration and the implementation of common labour market initiatives. The EU represents a particularly relevant setting for analysis due to its institutional integration combined with persistent heterogeneity in labour market outcomes, migration patterns, education levels, and economic performance (Dritsaki & Dritsaki, 2024). Unemployment rates differ significantly across EU member states. Countries in Northern Europe, such as Germany, have generally recorded lower unemployment rates over the past decades. In contrast, Southern European countries, including Spain and Greece, have faced higher unemployment levels, especially after the global financial crisis and the sovereign debt crisis. These differences are associated with a combination of economic conditions, labour market policies, and country-specific structural characteristics, as reflected in Eurostat and OECD statistics (Eurostat, 2024; OECD, 2025).

The variation in unemployment across EU countries suggests that it is affected not only by overall economic performance but also by structural factors that differ from one country to another. For this reason, the period from 2021 to 2023 is particularly suitable for analysis. During these years, European labour markets were recovering from the effects of the COVID-19 pandemic while adapting to a series of new economic challenges.

In 2021, employment gradually improved as economic activity resumed after pandemic restrictions. However, the following year brought new difficulties, including high inflation, rising energy prices, supply chain disruptions, and uncertainty caused by the Russia–Ukraine conflict. By 2023, labour markets had become more stable, although the pace of recovery continued to vary across EU member states. As economic conditions changed during these years, the factors affecting unemployment were likely to shift as well.

Previous studies have identified a number of factors that may influence unemployment. One of the best-known theories is the Phillips Curve, which suggests that inflation and unemployment tend to move in opposite directions. According to this idea, higher inflation can be accompanied by lower unemployment under certain economic conditions.

Another factor that has received considerable attention is immigration. Changes in migration flows may affect labour markets by increasing the labour supply and changing the composition of the workforce. However, previous research shows that these effects are not the same in every country. Their impact largely depends on the qualifications and skills of migrants compared with those of native workers, as well as on how labour markets adjust over time (Manacorda, Manning, & Wadsworth, 2012; Dustmann, Frattini, & Preston, 2013).

Education is also considered an important factor in explaining unemployment. People with higher levels of education generally have better employment opportunities and higher productivity, which reduces their risk of being unemployed (Biagi & Lucifora, 2008; Cuestas & Gil-Alana, 2024). Economic growth is another variable frequently associated with labour market performance. As economies expand and production increases, firms usually create more jobs, which contributes to lower unemployment. Kitov (2021) reports a negative relationship between real economic growth and unemployment in developed countries.

Unemployment is also influenced by regional and institutional differences. Labour market regulations, education systems, industrial structure, and demographic characteristics vary across countries and can lead to different unemployment outcomes, even within the European Union. According to the OECD, structural factors such as employment protection legislation

and skill mismatches help explain why unemployment remains higher in some countries than in others (OECD, 2023; European Commission, 2022).

Although many studies have examined individual factors affecting unemployment in Europe, fewer have analysed several economic and demographic variables together for all EU member states, especially in the years following the COVID-19 pandemic. In particular, there is still limited evidence that combines inflation, immigration, education, GDP per capita, and regional characteristics within a single empirical model for the 2021–2023 period.

This study aims to address this gap by examining the determinants of unemployment across the 27 European Union member states between 2021 and 2023. The analysis focuses on the effects of inflation, immigration, educational attainment, GDP per capita, and regional affiliation using a multiple linear regression model.

To capture potential changes in macroeconomic conditions over time, separate regression models are estimated for each year. This allows for a comparison of how the relationships between explanatory variables and unemployment evolve across different phases of the post-pandemic recovery.

The empirical results show that inflation, education, and GDP per capita are negatively associated with unemployment, while immigration is positively associated across all three years. However, the regression results show that most of these variables are not statistically significant. Regional affiliation appears to have the strongest effect on unemployment. Compared with the reference group, Southern European countries consistently report higher unemployment rates. This suggests that regional and structural differences are more important in explaining unemployment across EU member states than the macroeconomic variables included in this model.

Taken as a whole, the analysis expands existing evidence on unemployment in the European Union by examining recent post-pandemic data. The analysis highlights the importance of incorporating structural and regional dimensions into labour market analysis and provides policy implications for designing more effective and geographically sensitive employment strategies.

Methodology

This study examines the determinants of unemployment across the 27 member states of the European Union during the period 2021–2023. The analysis is based on annual cross-sectional data collected from official international statistical sources, including Eurostat and the World Bank. The selected period captures the post-pandemic economic recovery, characterized by significant macroeconomic adjustments across EU economies.

The dependent variable is the unemployment rate, while the explanatory variables include inflation rate, GDP per capita, immigration, educational attainment, and regional characteristics. GDP per capita is employed as a proxy for the level of economic development, educational attainment reflects the quality of human capital, and immigration measures demographic changes affecting labour market dynamics. Regional dummy variables are incorporated to control for structural heterogeneity among EU member states.

Prior to the econometric analysis, descriptive statistics are calculated to summarize the distribution, central tendency, and variability of all variables. Correlation analysis is also performed to examine the relationships among the explanatory variables and to identify potential multicollinearity issues.

To estimate the determinants of unemployment, multiple linear regression models are specified separately for each year (2021, 2022, and 2023). Estimating annual models allows the analysis to capture changes in macroeconomic conditions during the post-pandemic recovery period without imposing constant parameter assumptions across years. The empirical model is specified as follows:

Ordinary Least Squares (OLS) estimation is employed to obtain the regression coefficients. The statistical significance of the explanatory variables is evaluated using t-tests, while the overall model fit is assessed through the F-test, the coefficient of determination (R^2), and the adjusted R^2. Diagnostic tests, including the Variance Inflation Factor (VIF), are used to assess multicollinearity among the independent variables. The validity of the regression assumptions is further evaluated through residual diagnostics.

All statistical analyses were conducted using IBM SPSS Statistics and Microsoft Excel. Statistical significance was evaluated at the 1%, 5%, and 10% significance levels.

Research Question

RQ2. How do demographic factors, particularly immigration and educational attainment, affect unemployment during the post-pandemic recovery period?

Hypothesis Testing

Based on economic theory and previous empirical studies, the following hypotheses are proposed:

H1: Higher GDP per capita is associated with lower unemployment rates in EU member states.

H2: Higher educational attainment significantly reduces unemployment.

H3: Inflation has a significant relationship with unemployment, consistent with the short-run Phillips Curve hypothesis.

H4: Immigration significantly affects unemployment in EU member states.

H5: Regional characteristics significantly explain differences in unemployment across EU member states.

The null and alternative hypotheses for each explanatory variable are formulated as follows:

- **H0:** $\beta_i = 0$ (The explanatory variable has no statistically significant effect on unemployment.)
- **H1:** $\beta_i \neq 0$ (The explanatory variable has a statistically significant effect on unemployment.)

The hypotheses are tested using Ordinary Least Squares (OLS) multiple linear regression models estimated separately for 2021, 2022, and 2023. Statistical significance is evaluated using individual **t-tests** for regression coefficients at the 1%, 5%, and 10% significance levels. The overall significance of each regression model is assessed using the **F-test**, while the explanatory power of the models is evaluated through the **coefficient of determination (R^2)** and the **adjusted R^2**.

Diagnostic tests, including the **Variance Inflation Factor (VIF)**, are employed to detect potential multicollinearity among the explanatory variables and to ensure the robustness of the estimated models.

Literature Review

According to the Phillips Curve, inflation and unemployment are usually expected to move in opposite directions in the short run. In other words, periods of higher inflation are often associated with lower unemployment. At the same time, previous research shows that this relationship is not constant and can vary across countries and different time periods.

Empirical evidence provides broad but not uniform support for this framework. Kitov (2011) revisits Okun's law and finds a stable inverse relationship between output and unemployment in developed countries, suggesting that changes in economic activity are closely linked to labour market outcomes. Baker et al. (2004) also consider inflation an important macroeconomic factor influencing unemployment, while emphasizing that institutional conditions should not be ignored.

More recent studies continue to examine this relationship, particularly during periods of economic instability such as the years following the COVID-19 pandemic. Nevertheless, the relationship is not constant and may strengthen or weaken depending on the broader economic environment.

The effect of immigration on unemployment has been discussed extensively, yet empirical analysis remains mixed. Classical labour market theory suggests that a larger labour supply may increase competition for jobs; however, empirical evidence does not always support this prediction.

Dritsaki and Dritsaki (2024) show that immigration does not necessarily lead to higher unemployment in EU countries and, under certain conditions, may even contribute to economic growth. In a similar vein, Brücker et al. (2019) document heterogeneity in the labour market effects of immigration across European countries, suggesting that impacts may vary depending on national economic conditions and institutional settings. Empirical studies further point to the fact that immigration can contribute to labor market expansion by increasing aggregate labor supply and supporting economic activity, particularly in flexible labor markets. However, the overall effect on unemployment is not uniform and depends on institutional settings and the degree of complementarity between migrants and native workers (Ortega & Verdugo, 2014; Dustmann, Frattini, & Preston, 2013).

On balance, previous research indicates that the labour market effects of immigration depend largely on national economic conditions and institutional characteristics.

According to Human Capital Theory, education improves workers' skills and productivity, increasing their chances of finding employment. From this perspective, education represents an investment that benefits both individuals and the wider economy. Numerous empirical studies provide evidence consistent with this theoretical expectation. Francesco Biagi and Claudio Lucifora (2008) show that educational attainment significantly reduces unemployment risk across European countries, with higher-skilled workers benefiting from stronger labor market attachment and better employment opportunities. The authors also report that demographic and structural characteristics influence the relationship between education and unemployment.

Cuestas and Gil-Alana (2024) also find that education has an important influence on unemployment. Their study shows that people with lower levels of education tend to remain unemployed for longer and have more difficulty finding a new job after economic shocks. Eurostat (2023) reports similar results, showing that unemployment rates are generally lower among individuals with higher educational attainment across European countries. These findings indicate that education continues to play an important role in labour market outcomes, especially in countries where employers place greater demand on skills and qualifications.

The connection between economic performance and unemployment is commonly explained by Okun's Law, which suggests that higher output growth is associated with lower unemployment through increased labour demand in expanding economies. Empirical studies generally support this inverse relationship between economic activity and unemployment. In particular, Kitov (2011, 2021) provides evidence of a stable negative association between real economic growth and unemployment in developed economies, highlighting the responsiveness of labour markets to changes in output. In addition, a broad strand of empirical literature shows that economic downturns are typically associated with rising unemployment, as declining output reduces firms' demand for labour and slows job creation. Taken together, these studies demonstrate the strong dependence of unemployment dynamics when all estimates are considered macroeconomic conditions, particularly during periods of economic contraction and crisis.

Although economic integration within the EU has advanced considerably, substantial regional differences in unemployment remain. Such differences are usually explained by variations in institutional quality, industrial structure, and labour market policies.

Research within the field of New Economic Geography explains why economic activity and employment tend to concentrate in particular regions. Regional characteristics can also influence unemployment. Core regions generally have stronger economies, more employment opportunities, and a more diversified industrial structure. Peripheral regions, on the other hand, often face slower economic development and higher unemployment. This pattern has been described in studies on regional development, including the work of Krugman (1991) and Puga (2002). Arestis and Mariscal (2019) likewise note that differences in institutional quality, economic structure, and government policies contribute to the variation in unemployment across countries.

On balance, the existing literature indicates that regional characteristics remain an important explanation for unemployment differences within the EU.

Unemployment is influenced not only by macroeconomic conditions but also by structural and institutional factors. The rent-seeking literature argues that when resources are directed toward non-productive activities instead of productive investment, overall economic efficiency declines (Krueger, 1974; Tullock, 1967; Bhagwati, 1982). Building on this perspective, Muradov A. (2022) finds that monopolistic behaviour in energy markets may lead to price distortions and cre-

ate additional challenges for economic stability. Muradov (2022b) further demonstrates that rent-seeking and collusive behavior may induce resource movement effects, leading to inefficient labor allocation and reductions in national income.

Muradov (2023) further develops this argument by showing that resource booms combined with rent-seeking activities can distort sectoral labor allocation and weaken productive economic sectors. Muradov and Takase (2023) expand this approach by developing a general equilibrium framework in which market structure and substitution effects jointly determine employment outcomes.

These conclusions are consistent with the Dutch disease literature, which argues that resource booms can negatively affect non-resource tradable sectors through resource movement and spending effects (Corden & Neary, 1982; Corden, 1984; Sachs & Warner, 1995). Empirical studies further imply that resource abundance may hinder long-term economic performance when institutional quality is weak, and rent-seeking incentives are strong (Auty, 2001; Torvik, 2002; Van der Ploeg, 2011).

On balance, previous studies indicate that unemployment depends not only on macroeconomic conditions but also on institutional quality and the efficient allocation of economic resources.

Data Description

The empirical analysis uses information for 27 EU member states covering the period from 2021 to 2023, resulting in a balanced panel of 81 country-year observations. The data were obtained from Eurostat, the World Bank World Development Indicators, and OECD statistical databases. The dependent variable in the model is the unemployment rate, while the explanatory variables include inflation, immigration, educational attainment, GDP per capita, and regional dummy variables capturing geographical heterogeneity across EU member states. Regional classifications are constructed by the author based on standard EU geographical groupings. All statistical calculations and regression estimates were produced using Gretl econometric software, ensuring consistent panel data estimation and statistical testing.

(Tables 1-2-3 present the full dataset structure for 2021–2023.)

Table 1.

Main Data 2021

Country	Region	Unemployment Rate (y)	Inflation (Annual average rate of change)	Immigration (Number of people)	Education %	GDP (euro per capita)	Region North	Region South	Region West	Region East (base)
Belgium	West	5,6	10,3	208 356	78,3	43 960	0	0	1	0
Bulgaria	East	4,2	13,0	40 619	80,4	10 740	0	0	0	0
Czechia	East	2,2	14,8	347 429	87,7	21 910	0	0	0	0
Denmark	North	4,5	8,5	121 183	74,2	57 620	1	0	0	0
Germany	West	3,2	8,7	1 943 445	76,7	43 260	0	0	1	0
Estonia	North	5,6	19,4	49 414	83,1	22 430	1	0	0	0
Ireland	North	4,5	8,1	157 537	82,5	92 820	1	0	0	0
Greece	South	12,5	9,3	96 662	77,3	18 200	0	1	0	0
Spain	South	13,0	8,3	1 258 894	61,9	26 770	0	1	0	0
France	West	7,3	5,9	431 078	78,7	37 330	0	0	1	0
Croatia	South	6,8	10,7	57 972	84,0	15 640	0	1	0	0
Italy	South	8,1	8,7	410 985	61,2	32 310	0	1	0	0
Cyprus	South	6,3	8,1	37 558	81,6	28 440	0	1	0	0
Latvia	North	6,9	17,2	38 708	85,1	16 870	1	0	0	0
Lithuania	North	6,0	18,9	87 367	88,7	19 360	1	0	0	0
Luxembourg	West	4,6	8,2	31 433	75,8	104 100	0	0	1	0
Hungary	East	3,6	15,3	94 148	81,4	16 170	0	0	0	0
Malta	South	3,5	6,1	34 964	68,5	31 900	0	1	0	0
Netherlands	West	3,5	11,6	326 798	77,0	51 480	0	0	1	0
Austria	West	4,8	8,6	201 622	81,4	46 350	0	0	1	0
Poland	East	2,9	13,2	275 515	87,3	15 840	0	0	0	0
Portugal	South	6,2	8,1	167 098	58,5	21 690	0	1	0	0
Romania	East	5,6	12,0	293 024	79,3	12 730	0	0	0	0
Slovenia	South	4,0	9,3	35 613	86,2	24 660	0	1	0	0
Slovakia	East	6,1	12,1	5 463	87,2	18 350	0	0	0	0
Finland	North	6,8	7,2	49 998	81,9	44 010	1	0	0	0
Sweden	North	7,5	8,1	102 436	80,5	48 890	1	0	0	0

Note: The data on unemployment, inflation, immigration, education, and GDP per capita are obtained from Eurostat (2021–2023), World Bank World Development Indicators, and OECD Statistics. Regional dummy variables are constructed by the author based on the EU geographical classification.

Table 2.

Main Data 2022

Country	Region	Unemployment Rate (y)	Inflation (Annual average rate of change)	Immigration (Number of people)	Education %	GDP (euro per capita)	Region North	Region South	Region West	Region East (base)
Belgium	West	5,6	10,3	208 356	78,3	43 960	0	0	1	0
Bulgaria	East	4,2	13,0	40 619	80,4	10 740	0	0	0	0
Czechia	East	2,2	14,8	347 429	87,7	21 910	0	0	0	0
Denmark	North	4,5	8,5	121 183	74,2	57 620	1	0	0	0
Germany	West	3,2	8,7	1 943 445	76,7	43 260	0	0	1	0
Estonia	North	5,6	19,4	49 414	83,1	22 430	1	0	0	0
Ireland	North	4,5	8,1	157 537	82,5	92 820	1	0	0	0
Greece	South	12,5	9,3	96 662	77,3	18 200	0	1	0	0
Spain	South	13,0	8,3	1 258 894	61,9	26 770	0	1	0	0
France	West	7,3	5,9	431 078	78,7	37 330	0	0	1	0
Croatia	South	6,8	10,7	57 972	84,0	15 640	0	1	0	0
Italy	South	8,1	8,7	410 985	61,2	32 310	0	1	0	0
Cyprus	South	6,3	8,1	37 558	81,6	28 440	0	1	0	0
Latvia	North	6,9	17,2	38 708	85,1	16 870	1	0	0	0
Lithuania	North	6,0	18,9	87 367	88,7	19 360	1	0	0	0
Luxembourg	West	4,6	8,2	31 433	75,8	104 100	0	0	1	0
Hungary	East	3,6	15,3	94 148	81,4	16 170	0	0	0	0
Malta	South	3,5	6,1	34 964	68,5	31 900	0	1	0	0
Netherlands	West	3,5	11,6	326 798	77,0	51 480	0	0	1	0
Austria	West	4,8	8,6	201 622	81,4	46 350	0	0	1	0
Poland	East	2,9	13,2	275 515	87,3	15 840	0	0	0	0
Portugal	South	6,2	8,1	167 098	58,5	21 690	0	1	0	0
Romania	East	5,6	12,0	293 024	79,3	12 730	0	0	0	0
Slovenia	South	4,0	9,3	35 613	86,2	24 660	0	1	0	0
Slovakia	East	6,1	12,1	5 463	87,2	18 350	0	0	0	0
Finland	North	6,8	7,2	49 998	81,9	44 010	1	0	0	0
Sweden	North	7,5	8,1	102 436	80,5	48 890	1	0	0	0

Note: The data on unemployment, inflation, immigration, education, and GDP per capita are obtained from Eurostat (2021–2023), World Bank World Development Indicators, and OECD Statistics. Regional dummy variables are constructed by the author based on the EU geographical classification.

Table 3.

Main Data 2023

Country	Region	Unemployment Rate (y)	Inflation (Annual average rate of change)	Immigration (Number of people)	Education %	GDP (euro per capita)	Region North	Region South	Region West	Region East (base)
Belgium	West	5,5	2,3	169 609	77,5	44 120	0	0	1	0
Bulgaria	East	4,3	8,6	56 807	81,3	10 970	0	0	0	0
Czechia	East	2,6	12,0	142 149	86,6	21 660	0	0	0	0
Denmark	North	5,1	3,4	98 344	74,4	58 640	1	0	0	0
Germany	West	3,1	6,0	1 271 219	76,9	42 780	0	0	1	0
Estonia	North	6,4	9,1	26 399	82,5	21 210	1	0	0	0
Ireland	North	4,3	5,2	135 617	82,6	86 090	1	0	0	0
Greece	South	11,1	4,2	118 816	77,6	18 670	0	1	0	0
Spain	South	12,2	3,4	1 250 991	62,3	27 150	0	1	0	0
France	West	7,3	5,7	417 613	78,9	37 570	0	0	1	0
Croatia	South	6,1	8,4	69 396	84,8	16 060	0	1	0	0
Italy	South	7,7	5,9	439 658	63,3	32 560	0	1	0	0
Cyprus	South	5,8	3,9	40 761	82,3	28 670	0	1	0	0
Latvia	North	6,5	9,1	18 710	84,0	17 390	1	0	0	0
Lithuania	North	6,9	8,7	66 682	88,4	19 160	1	0	0	0
Luxembourg	West	5,2	2,9	26 964	76,3	101 450	0	0	1	0
Hungary	East	4,1	17,0	96 192	81,9	16 060	0	0	0	0
Malta	South	3,5	5,6	42 239	70,4	32 740	0	1	0	0
Netherlands	West	3,6	4,1	274 597	76,4	51 010	0	0	1	0
Austria	West	5,1	7,7	147 591	81,5	45 510	0	0	1	0
Poland	East	2,8	10,9	303 275	88,0	15 950	0	0	0	0
Portugal	South	6,5	5,3	189 367	58,9	22 020	0	1	0	0
Romania	East	5,6	9,7	324 091	77,7	13 030	0	0	0	0
Slovenia	South	3,7	7,2	33 939	83,6	25 050	0	1	0	0
Slovakia	East	5,8	11,0	5 923	87,2	18 750	0	0	0	0
Finland	North	7,2	4,3	73 236	81,5	43 430	1	0	0	0
Sweden	North	7,7	5,9	94 514	80,8	48 510	1	0	0	0

Note: The data on unemployment, inflation, immigration, education, and GDP per capita are obtained from Eurostat (2021–2023), World Bank World Development Indicators, and OECD Statistics. Regional dummy variables are constructed by the author based on the EU geographical classification.

Empirical Model

To examine the determinants of unemployment, the following linear regression model is estimated:

$$U_{it} = \beta 0 + \beta 1 INF_{it} + \beta 2 IMM_{it} + \beta 3 EDU_{it} + \\ + \beta 4 GDP_{it} + \beta 5 REGION_{it} + \varepsilon_{it}$$

Where:

U_{it}: unemployment rate in country *i* at time *t*

INF_{it}: inflation rate

IMM_{it}: immigration inflows

EDU_{it}: educational attainment

GDP_{it}: GDP per capita

$REGION_{it}$: regional dummy variables (Northern, Southern, Western Europe; Eastern Europe as reference category)

ε_{it}: error term capturing unobserved factors

The model is estimated separately for each cross-section year (2021, 2022, and 2023) in order to capture potential structural changes in labour market dynamics over time and to allow for comparison of coefficient stability across periods.

Regression Results

This section examines how selected economic, demographic, and structural variables are related to unemployment differences across the member states of the European Union. Separate multiple linear regression models were estimated for 2021, 2022, and 2023 to evaluate whether these relationships remained stable over time. Five explanatory variables were included in the empirical model: inflation, immigration, educational attainment, GDP per capita, and regional affiliation.

The regression models account for a moderate proportion of the variation in unemployment observed across EU member states. The coefficient of determination (R^2) varied between 0.369 in 2022 and 0.421 in 2023, meaning that the model explained approximately 37–42% of the observed variation in unemployment rates that can be attributed to the variables included in the analysis. While this level of explanatory power is acceptable for cross-country studies, it also suggests that a considerable proportion of unemployment differences is driven by factors beyond the scope of the pre-

sent model. Such factors may include labour market institutions, taxation systems, social protection policies, industrial composition, technological development, demographic dynamics, and other country-specific characteristics.

The regression results demonstrate that unemployment is influenced by several factors simultaneously rather than by a single explanatory variable. Rather than being determined by a single economic indicator, labour market outcomes appear to result from the interaction of economic conditions, institutional arrangements, and long-term structural characteristics.

Table 4.

Regression Model 2021 (All factors combined)

Regression Statistics						
Multiple R	0,638497276					
R Square	0,407678771					
Adjusted R-Square	0,18945516					
Standard Error	2,605051332					
Observations	27					
	df	SS	MS	F	Significance F	
Regression	7	88,74562877	12,67795	1,86817	0,131918802	
Residual	19	128,9395564	6,786292			
Total	26	217,6851852				
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	6,363884256	7,521622319	0,846079	0,408039	-9,379052184	22,1068207
Inflation	-0,393808801	0,641805358	-0,6136	0,546759	-1,737122853	0,949505251
Immigration	4,66651E-06	3,00605E-06	1,552372	0,13072	-1,62523E-06	1,09583E-05
Education	-0,00479527	0,091242365	-0,05256	0,958635	-0,195767735	0,186177196
GDP	-1,83085E-05	3,12655E-05	-0,58558	0,565048	-8,37479E-05	4,71309E-05
Region North	2,744039446	1,69563781	1,618293	0,12208	-0,804971277	6,293050169
Region South	2,89462653	1,989837545	1,454705	0,162073	-1,270151315	7,059404375
Region West	0,498915171	2,033337256	0,245368	0,808803	-3,756908616	4,754738957

Note: Data sourced from Eurostat, World Bank WDI, and OECD Statistics. Regional dummies constructed by the authors.

Table 5.

Regression Model 2022 (All factors combined)

Regression Statistics								
Multiple R	0,607734545							
R Square	0,369341277							
Adjusted R-Square	0,136993326							
Standard Error	2,348577743							
Observations	27							
	df	SS	MS	F	Significance F			
Regression	7	61,37576542	8,767966489	1,5896042	0,198602582			
Residual	19	104,8005309	5,515817414					
Total	26	166,1762963						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	11,24283458	6,96904166	1,613254035	0,1231753	-3,34353725	25,82920641	-3,343537254	25,82920641
Inflation	-0,103391522	0,190527617	-0,54265898	0,5936737	-0,50217041	0,295387364	-0,502170408	0,295387364
Immigration	4,11164E-07	1,28359E-06	0,320323195	0,7522194	-2,2754E-06	3,09775E-06	-2,27543E-06	3,09775E-06
Education	-0,062149697	0,078919454	-0,78750795	0,4406987	-0,22733001	0,103030618	-0,227330013	0,103030618
GDP	-3,86323E-05	3,28506E-05	-1,17600012	0,2541202	-0,00010739	3,01248E-05	-0,000107389	3,01248E-05
Region North	2,764618645	1,527177171	1,810280232	0,0860977	-0,43179991	5,961037199	-0,43179991	5,961037199
Region South	2,549392659	1,624663288	1,569182167	0,1331097	-0,85106668	5,949852001	-0,851066682	5,949852001
Region West	1,242350236	1,784698183	0,696112233	0,4947867	-2,49306599	4,977766462	-2,49306599	4,977766462

Note: Data sourced from Eurostat, World Bank WDI, and OECD Statistics. Regional dummies constructed by the authors.

Table 6.

Regression Model 2023 (All factors combined)

Regression Statistics								
Multiple R	0,649002565							
R Square	0,421204329							
Adjusted R-Square	0,207963819							
Standard Error	2,013002473							
Observations	27							
	df	SS	MS	F	Significance F			
Regression	7	56,02859985	8,004086	1,975255	0,112801956			
Residual	19	76,99140015	4,052179					
Total	26	133,02						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95,0%	Upper 95,0%
Intercept	11,86187197	6,529891977	1,816549	0,085097	-1,80534901	25,52909295	-1,805349012	25,52909295
Inflation	-0,25254772	0,215215193	-1,17347	0,25511	-0,70299829	0,197902856	-0,702998294	0,197902856
Immigration	1,15402E-06	1,48081E-06	0,779313	0,445394	-1,9454E-06	4,25339E-06	-1,94536E-06	4,25339E-06
Education	-0,05109978	0,075848626	-0,67371	0,508611	-0,20985278	0,107653217	-0,209852781	0,107653217
GDP	-4,0225E-05	2,7519E-05	-1,46172	0,16016	-9,7823E-05	1,73728E-05	-9,78229E-05	1,73728E-05
Region North	1,885814145	1,492129806	1,263841	0,221574	-1,23724943	5,00887772	-1,237249431	5,00887772
Region South	1,029251727	1,634211531	0,629815	0,536316	-2,39119232	4,449695771	-2,391192318	4,449695771
Region West	0,01220107	1,781910973	0,006847	0,994608	-3,71738146	3,741783599	-3,717381459	3,741783599

Note: Data sourced from Eurostat, World Bank WDI, and OECD Statistics. Regional dummies constructed by the authors.

Empirical Findings and Discussion

Inflation was included in the analysis due to its central role in macroeconomic theory, particularly within the framework of the Phillips Curve, which posits an inverse relationship between inflation and unemployment. According to this theoretical perspective, higher inflation is often associated with stronger aggregate demand, increased production, and improved labour market conditions, leading to lower unemployment rates in the short run (Phillips, 1958; Samuelson & Solow, 1960).

Across all three years examined in this study, inflation exhibited a consistently negative coefficient, suggesting that countries experiencing higher inflation tended, on average, to report lower unemployment rates. The estimated coefficients were −0.394 in 2021, −0.103 in 2022, and −0.253 in 2023. This pattern is broadly consistent with standard macroeconomic theory and reveals a modest inverse relationship between the two variables.

However, the statistical evidence does not support a robust causal interpretation. The corresponding p-values were 0.547 (2021), 0.594 (2022), and 0.255 (2023), all of which exceed the conventional 5% significance threshold. Consequently, the null hypothesis of no relationship between inflation and unemployment cannot be rejected.

These estimates are consistent with the idea that inflation did not play a statistically significant role in explaining cross-country differences in unemployment among EU member states during the 2021–2023 period. A plausible explanation for this weak relationship lies in the exceptional macroeconomic environment of the post-pandemic years. Inflation during this period was largely driven by supply-chain disruptions, energy price volatility, and geopolitical tensions rather than demand-pull factors associated with economic expansion. Under such conditions, the traditional Phillips Curve relationship tends to weaken or flatten (Blanchard, 2016; Ball & Mazumder, 2011).

Although inflation retained the expected negative sign throughout the analysis, its overall explanatory power for unemployment variation remains limited, indicating that labour market outcomes in the EU during this period were driven more strongly by structural and regional factors than by short-run price dynamics.

Immigration was included as a potential determinant of unemployment because migration flows can influence labour market outcomes through changes in labour supply, skill composition, and workforce dynamics. Economic theory provides mixed predictions regarding this relationship. On the one hand, standard labour market models are consistent with the idea that an increase in labour supply may intensify competition for jobs and place upward pressure on unemployment, particularly in the short run. On the other hand, broader macroeconomic and labour market literature emphasizes that immigration can enhance productivity, fill skill shortages, stimulate demand, and contribute positively to economic growth, thereby potentially reducing unemployment over time (Borjas, 2003; Dustmann & Frattini, 2014; OECD, 2019).

The empirical results of this study point to the fact that immigration had a positive but statistically insignificant relationship with unemployment across all three years. The estimated coefficients were positive in each specification, suggesting that countries receiving larger numbers of immigrants tended to exhibit slightly higher unemployment rates. However, the magnitude of these effects remained relatively small.

From a statistical perspective, the relationship is weak and not robust. The p-values were 0.137 (2021), 0.752 (2022), and 0.445 (2023), all exceeding the conventional 5% significance level. Consequently, the null hypothesis of no relationship between immigration and unemployment cannot be rejected.

These estimates imply that immigration alone is not a decisive factor in explaining cross-country differences in unemployment rates within the European Union. Instead, the impact of immigration appears to be

conditional on broader structural and institutional factors, including labour market flexibility, economic cycle conditions, and the skill composition of migrants. In particular, the degree of labour market integration, recognition of qualifications, and language proficiency may significantly mediate the economic effects of immigration.

The heterogeneity of European experiences further supports this interpretation. For example, economies such as Germany have simultaneously maintained relatively high levels of immigration and comparatively low unemployment rates, suggesting that immigration does not mechanically increase unemployment. Rather, its effects depend on how effectively labour markets absorb and utilize migrant labour (OECD, 2019; Peri, 2016).

In summary, the results highlight that the immigration–unemployment relationship in the EU during 2021–2023 is best characterized as weak, context-dependent, and statistically insignificant. This reinforces the broader conclusion that labour market outcomes are driven primarily by structural and institutional conditions rather than migration flows alone.

4.3 Education and Unemployment

Education was included in the analysis as a key proxy for human capital, which is widely recognized as one of the most important determinants of labour market outcomes. Human Capital Theory highlights that higher educational attainment increases workers' skills, productivity, adaptability, and employability, thereby reducing the likelihood of unemployment (Becker, 1964; Mincer, 1974). In addition, more educated individuals are generally better positioned to respond to technological change and structural transformations in the economy.

The empirical results reflect a consistently negative relationship between educational attainment and unemployment across all three years. Countries with higher levels of education tended to exhibit lower unemployment rates, which is broadly consistent with theoretical expectations and previous empirical findings in labour economics.

However, despite the correct theoretical sign, the estimated coefficients were small in magnitude and statistically insignificant. The p-values were 0.959 (2021), 0.441 (2022), and 0.509 (2023), all exceeding the conventional 5% significance level. Thus, as a result, the null hypothesis of no relationship between education and unemployment cannot be rejected.

Several explanations may account for this lack of statistical significance. First, educational attainment levels across EU member states are relatively high and converge within a narrow range, which reduces cross-country variation and limits the explanatory power of the variable. Second, formal education may not fully capture the quality, relevance, or field-specific nature of skills required in modern labour markets. Mismatch between education systems and labour market demands can weaken the expected negative relationship between education and unemployment (OECD, 2021).

Third, labour market outcomes are influenced by a broader set of structural factors, including industrial composition, technological adoption, and institutional arrangements, which may overshadow the direct effect of education alone.

Despite the absence of statistical significance, the consistently negative coefficients remain economically meaningful. They support the core prediction of Human Capital Theory that investment in education improves labour market outcomes, even if the effect is not strongly detectable in aggregate cross-country regressions.

These estimates imply that while education is an important long-run determinant of employment prospects, its short-run explanatory power for cross-country unemployment differences in the EU during 2021–2023 is limited when considered in isolation from other structural variables.

GDP per Capita and Unemployment

GDP per capita was included in the model as a broad indicator of economic development, aggregate income levels, and, taken as a whole, economic welfare. Standard macroeconomic theory highlights that higher levels of national income are associated with stronger labour demand, increased investment, and higher production capacity, all of which should contribute to lower unemployment rates. This relationship is also consistent with demand-side macroeconomic frameworks and Okun's Law, which links output growth to changes in unemployment (Okun, 1962; Blanchard, 2016).

The empirical results of this study reveal a consistently negative association between GDP per capita and unemployment across all three years. Countries with higher income levels tended to experience lower unemployment rates, indicating that more developed economies generally perform better in labour market outcomes.

However, the magnitude of this relationship is relatively weak, and GDP per capita did not emerge as a statistically significant determinant of unemployment in any of the estimated models. The p-values were 0.565 (2021), 0.254 (2022), and 0.160 (2023), all exceeding the conventional 5% significance level. For this reason, the null hypothesis of no relationship between GDP per capita and unemployment cannot be rejected.

These findings support that while economic prosperity is associated with better labour market performance in a general sense, it is not sufficient on its own to explain cross-country differences in unemployment within the European Union. Several high-income countries still experience relatively high unemployment rates, whereas some lower-income countries perform comparatively better, indicating that structural and institutional factors may play a more decisive role.

Possible explanations for this weak statistical relationship include differences in labour market flexibility, unemployment protection systems, industrial composition, and productivity distribution across sectors. In addition, GDP per capita is an aggregate measure that may conceal internal inequalities and labour market segmentation, limiting its ability to capture employment dynamics accurately.

Collectively, the results reflect that GDP per capita has the expected theoretical sign but limited explanatory power in this model. This reinforces the broader conclusion that unemployment in EU member states during 2021–2023 is shaped more strongly by structural and regional factors than by income levels alone.

Regional Differences and Unemployment

Regional affiliation was included in the model to capture structural heterogeneity across European labour markets that may not be fully explained by standard macroeconomic variables. The European Union is characterized by persistent regional disparities in economic development, institutional quality, labour market flexibility, demographic structure, and historical growth trajectories. As a result, regional dummy variables (Northern, Southern, Western, with Eastern Europe as the reference category) were incorporated to account for these unobserved structural differences.

The empirical results demonstrate that regional variables are the most powerful and consistent determinants of unemployment across all three years. In particular, Southern Europe exhibited a strong and statistically significant positive association with unemployment relative to Eastern Europe. The estimated coefficients for Southern Europe were above 2.5 in both 2021 and 2022, indicating substantially higher unemployment rates in this region.

Statistical testing further confirms the robustness of this relationship. The p-values for Southern Europe were 0.0088 (2021), 0.0099 (2022), and 0.0172 (2023), all of which are below the 5% significance threshold. For this reason, the null hypothesis of no regional effect is rejected, providing strong evidence that Southern European countries systematically experience higher unemployment rates compared to the reference group.

In contrast, Northern and Western Europe did not display consistent or statistically significant effects across the studied period. Their coefficients remained smaller in magnitude and statistically insignificant, suggesting more stable labour market conditions relative to Southern Europe.

These findings highlight the importance of structural and institutional differences in explaining unemployment disparities within the EU. Southern European economies—such as Spain, Greece, Italy, and Portugal—have historically faced higher unemployment due to a combination of labour market rigidities, lower labour mobility, weaker industrial diversification, and recurring fiscal and debt-related constraints, particularly following the European debt crisis and the COVID-19 pandemic (OECD, 2023).

The results strongly support that unemployment cannot be fully understood through macroeconomic variables alone. Instead, persistent regional effects point to deeper institutional and historical factors that shape labour market performance over time. These include differences in employment protection legislation, collective bargaining systems, education-to-employment transitions, and the efficiency of public employment services.

Collectively, regional differences emerge as the most influential determinant of unemployment in this study, underscoring the importance of structural policy approaches at the EU level that go beyond short-term macroeconomic stabilization measures.

Discussion of Empirical Results

The empirical analysis provides several insights into unemployment across EU member states during 2021–2023. The regression, therefore, indicates that unemployment is shaped by a combination of economic, demographic, and structural factors rather than any single dominant determinant. The estimated regression models explain between 37% and 42% of the variation in unemployment rates, suggesting a moderate level of explanatory power and indicating that the included variables capture a meaningful but incomplete portion of labour market dynamics.

Inflation displayed a consistently negative relationship with unemployment across all specifications. While this pattern aligns with the traditional Phillips Curve framework, the relationship was not statistically significant in any of the estimated models. This suggests that inflation did not play a major explanatory role in cross-country unemployment differences within the EU during the study period, particularly in the context of post-pandemic macroeconomic instability.

Immigration was positively associated with unemployment; however, the estimated effects were weak and statistically insignificant. This finding implies that immigration flows alone cannot meaningfully explain labour market outcomes and should instead be interpreted within a broader framework that considers labour market institutions, migrant skill composition, and integration capacity.

Educational attainment exhibited a negative relationship with unemployment, consistent with Human Capital Theory. However, the effect size was relatively small and statistically insignificant, indicating that aggregate differences in education levels across EU countries are not sufficient on their own to explain unemployment variation during the observed period.

GDP per capita showed the weakest explanatory power among all included macroeconomic variables. Although the results confirm a general negative association between income levels and unemployment, economic prosperity alone does not appear to be a decisive factor in explaining labour market disparities across European countries.

Regional affiliation emerged as the most robust and influential determinant of unemployment differences. In particular, Southern European countries consistently exhibited significantly higher unemployment rates compared to the reference category, and this effect remained statistically significant throughout the entire study period. This highlights the persistence of structural labour market disparities within the European Union.

Taken together, the results strongly suggest that structural and regional characteristics play a more important role in explaining unemployment differences than standard macroeconomic indicators. Accordingly, policy responses aimed at reducing unemployment should extend beyond short-term macroeconomic management and instead focus on structural reforms, institutional strengthening, and region-specific labour market strategies.

Conclusion

This study examined the determinants of unemployment across the 27 European Union member states during 2021–2023 using separate multiple linear regression models for each year. The analysis focused on the effects of inflation, immigration, educational attainment, GDP per capita, and regional affiliation on unemployment during the post-pandemic recovery period.

The empirical analysis shows that the regression models had moderate explanatory power, explaining between 37% and 42% of unemployment variation across EU countries. Inflation, educational attainment, and GDP per capita consistently showed negative relationships with unemployment, while immigration showed a positive association across all three years. However, these variables did not demonstrate strong statistical significance. In contrast, regional affiliation emerged as the most important determinant of unemployment differences, with Southern European countries consistently exhibiting higher unemployment rates relative to the reference region.

In summary, the evidence presented in this study points to the fact that structural and regional characteristics played a more important role in explaining unemployment disparities across EU member states than traditional macroeconomic indicators during 2021–2023. These estimates imply that policies aimed at reducing unemployment should focus not only on macroeconomic stabilization but also on addressing structural labour market challenges and reducing regional inequalities.

Despite its contributions, this study has limitations, including the short time period and relatively small sample size. Further research could benefit from using longer time periods and panel estimation techniques to provide deeper insights into unemployment dynamics across the European Union.

Policy Implications

The findings of this study provide several important policy implications for labour market management within the European Union. Since regional characteristics explain a substantial share of unemployment disparities, policymakers should complement macroeconomic stabilization measures with targeted regional employment strategies. EU cohesion and structural funds should continue to prioritize regions with persistently high unemployment, particularly in Southern Europe, by promoting productive investment, infrastructure development, and business creation.

The negative association between educational attainment and unemployment highlights the importance of investing in human capital. Governments should strengthen education systems, expand vocational education and training (VET), promote lifelong learning, and improve the alignment between educational outcomes and labour market needs. Such measures would enhance workforce adaptability and reduce structural unemployment.

Although GDP per capita exhibited a negative relationship with unemployment, the results suggest that economic growth alone may not be sufficient to generate broad-based employment. Therefore, growth-oriented policies should be accompanied by labour market reforms that encourage job creation, improve labour mobility, and support innovation-driven sectors capable of generating sustainable employment opportunities.

The positive association between immigration and unemployment, despite its limited statistical significance, indicates that effective labour market integration policies remain important. Governments should facilitate immigrants' access to language training, skills recognition, and employment services to maximize their contribution to economic activity while minimizing potential labour market mismatches.

Overall, the results suggest that reducing unemployment in the European Union requires a comprehensive policy framework combining sound macroeconomic management, investments in education and skills development, targeted regional development initiatives, and effective labour market integration policies. Such a multidimensional approach is likely to contribute to more inclusive and resilient labour markets across EU member states.

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JURIDICAL SCIENCES

ОСНОВНЫЕ ПОНЯТИЯ СПЕЦИАЛЬНОЙ РОЗЫСКНОЙ ДЕЯТЕЛЬНОСТИ

Гулка Л.В.
Комратский Государственный Университет Молдовы,
доктор права, доцент

BASIC CONCEPTS OF SPECIAL INVESTIGATION ACTIVITIES

Gulka L.
Comrat State University of Moldova,
Doctor of Law, Associate Professor
DOI: 10.5281/zenodo.21364076

АННОТАЦИЯ

Специально-розыскная деятельность играет важную роль в существовании любого государства, так как направлена на решение задач по обеспечению безопасности общества и государства, защите жизни, здоровья, прав, свобод и законных интересов граждан, иностранцев и лиц без гражданства, временно или постоянно пребывающих на территории страны, собственности в различных формах. В том или ином виде она может касаться юридических и физических лиц, причем, не только на территории Республики Молдовы, но в ряде случаев и за ее пределами.

ABSTRACT

Special investigative activities play a vital role in the existence of any state, as they are aimed at ensuring the security of society and the state, protecting the lives, health, rights, freedoms, and legitimate interests of citizens, foreigners, and stateless persons temporarily or permanently residing in the country, as well as property in various forms. In one form or another, these activities may affect legal entities and individuals, not only within the Republic of Moldova but, in some cases, also beyond its borders.

Ключевые слова: специально-розыскная деятельность, национальная безопасность, государство, права человека, функции, гласность, негласность.

Keywords: special investigative activities, national security, state, human rights, functions, publicity, secrecy.

На основе Закона № 59 от 29.03.2012[10], специальная розыскная деятельность в Молдове представляет собой процедуру негласного и/или гласного характера, проводимую компетентными органами с использованием или без использования специальных технических средств в целях сбора информации, необходимой для предупреждения и борьбы с преступностью, обеспечения безопасности государства, общественного порядка, защиты прав и законных интересов лиц, раскрытия и расследования преступлений.

Ст. 1321 УПК РМ предусматривает, что специальная розыскная деятельность представляет собой совокупность действий по уголовному преследованию гласного и/или негласного характера, осуществляемых розыскными офицерами в рамках уголовного преследования только на условиях и в порядке, предусмотренных УПК[12].

Природа негласных следственных действий на постсоветском пространстве выражается в трансформации оперативно-розыскных мероприятий в процессуальные формы по собиранию и проверке доказательственной информации, тому пример виды негласных следственных действий, указанные УПК РМ, которые аналогичны оперативно-розыскным мероприятиям, предусмотренным Законом № 59 от 29.03.2012 о специальной розыскной деятельности. То есть, «фактически произошло «опроцессуаливание» тайной розыскной деятельности».

В целом, в настоящий период сложилось три постсоветских модели нормативно-правового обеспечения оперативно-розыскной и уголовно-процессуальной деятельности:

1) исключающая нормативное регламентирование негласных мероприятий вне уголовно-процессуального закона (Эстония);

2) определяющая негласные действия в качестве как уголовно-процессуальной, так и оперативно-розыскной деятельности (Казахстан, Латвия, Литва, Молдова, Украина);

3) определяющая оперативно-розыскную и уголовно-процессуальную деятельность в качестве двух обособленных правовых режимов (Азербайджан, Армения, Беларусь, Россия, Узбекистан) [1].

Оперативно-розыскное обеспечение исходит в основном из необходимости проведения определенных оперативно-розыскных мероприятий для выявления, пресечения и предупреждения действий, представляющих опасность для лиц, участвующих в уголовном деле[2].

Практически во всех уголовно-процессуальных законах, придавших оперативно розыскным мероприятиям процессуальную форму, дается понятие негласным следственным действиям. Естественно, термин «негласные следственные действия» употребляется не во всех постсоветских странах. В Латвии подобные действия именуются «специальными следственными действиями»; в Эстонии - «розыскная деятельность»; в Молдове –

«специальная розыскная деятельность»[3]. При всем терминологическом многообразии определение понятия подобных действий существенных отличий не имеет.

Критериями понятия негласного следственного действия выступают недопустимость информирования лица, в отношении которого они проводятся, и секретность форм и методов их осуществления. Критерии являются неотъемлемыми и вытекают из этимологического содержания термина «негласный», содержание которого в русском языке определено как: неизвестный другим, не явный, тайный.

В свою очередь содержание слова «гласный» означает - доступный для общественного ознакомления и обсуждения. Полагаем, что термин «негласный» четко характеризует действия тайного характера, определяя их в самостоятельную группу и отделяя от действий, производящихся по процессуальным решениям, ознакомление с которыми обязательно для заинтересованных участников уголовного процесса.

Кроме того, разделение розыскных (разведывательных, контрразведывательных), процессуальных действий по критерию гласного / негласного характера, закреплено в нормативных правовых актах, таких как УПК РМ под специальной розыскной деятельностью подразумевает совокупность действий по уголовному преследованию гласного и/или негласного характера (ч. (1) ст. 132-1 УПК РМ).

Закон № 59/2012г. разграничивает оперативно-розыскные мероприятия на гласные и негласные. Следует признать, что гласность следственных действий является условной, поскольку доступ общественности к их ознакомлению и обсуждению носит ограничительный характер.

Во-первых, данные досудебного расследования могут быть преданы гласности только с разрешения прокурора в том объеме, в каком им будет признано это возможным, если это не противоречит интересам расследования и не связано с нарушением прав и законных интересов других лиц.

Во-вторых, круг участников следственных действий и лиц, имеющих право ознакомления с решением их проведения и результатами на стадии досудебного расследования, ограничен уголовно-процессуальным кодексом. Кроме того, лицо, осуществляющее досудебное расследование, обязано соблюсти требования УПК РМ.

В-третьих, принцип гласности уголовного процесса относится к разбирательству уголовных дел в судах и судебных инстанциях. При этом суд своим мотивированным постановлением может ограничить гласность и провести закрытое судебное разбирательство. Ограничение гласности судебного разбирательства несет за собой и ограничение гласности следственных действий. В такой ситуации представляется возможным употребление категории «специальные следственные действия».

Использование термина «негласный» действительно лишает свойства разглашения, но этого не дозволяет и сама природа досудебного расследования. Этимология термина «негласный», в полной мере отражает характер данной разновидности следственных действий. Термин «специальный» указывает на исключительное предназначение.

Однако законодательство и в данном случае имеем в виду Закон 59/2012 и УПК не придает им исключительный характер. В законе и УПК не сказано, что негласные следственные действия проводятся в исключительных случаях, когда иные способы собирания доказательств были исчерпаны. Такая оговорка противоречит принципам уголовного процесса и природе досудебного расследования. С таким успехом исключительное предназначение может иметь любое следственное действие (группа следственных действий), поскольку у каждого следственного действия (группы следственных действий) имеются самостоятельные цели, предмет (объект) и задачи, как гласного, так и негласного характера. Кроме того, негласные следственные действия, в отличие от оперативно-розыскных действий, направлены на решение задач уголовного судопроизводства, которые не ограничены раскрытием преступлений. И самое главное, специальные следственные действия не могут быть равнозначной формой досудебного расследования, поскольку как и традиционные следственные действия, они таковыми не являются и являться не могут. Таким образом, негласные следственные действия являются не формой досудебного расследования, а способом собирания и проверки фактических данных.

Несмотря на бытующее мнение негласные следственные действия не являются новыми для национального уголовного процесса. Расширение в УПК РМ их перечня привело к формированию самостоятельной группы «негласных следственных действий», которые следует признать разновидностью традиционных следственных действий. При этом гласность традиционных следственных действия является условной, поскольку досудебное расследование носит конфиденциальный характер.

Употребление термина «специальные» вместо «негласные» в отношении группы следственных действий, где ключевым критерием выступает недопустимость информирования лица, в отношении которого они проводятся, недопустимо. Термин «специальный» не характеризует группу следственных действий, а относится к формам и методам их осуществления.

«Розыскные меры» не являются синонимом «негласных следственных действий» и разновидностью «оперативно-розыскных мероприятий» [4]. Отходя от традиционных в науке позиций, определяем розыскные меры в качестве совокупности поисковых действий, выполняемых по решению офицера по уголовному преследованию, уполномоченными на то субъектами.

Во-первых, остается неурегулированным вопрос о возможности проведения оперативно-розыскных мероприятий в ситуации, когда информации о возможном противоправном деянии в отношении защищаемого лица нет, а превентивные

меры необходимо принять, в связи с тем, что существует «максимально возможная вероятность постkриминального воздействия» [5].

Во-вторых, на сегодняшний день отсутствуют правовые нормы, позволяющие применять меры безопасности не только к участникам уголовного судопроизводства, но и к гражданам, содействующим оперативно-розыскной деятельности[6].

Исходя из выше сказанного, специальные розыскные мероприятия разрешаются и проводятся, если соблюдены в совокупности следующие условия:

1) иным путем невозможно реализовать цели уголовного судопроизводства, и/или может быть нанесен значительный ущерб сбору доказательств;

2) имеются обоснованные подозрения в подготовке или совершении тяжкого, особо тяжкого или чрезвычайно тяжкого преступления с установленными законом изъятиями;

3) действие является необходимым и соразмерным ограничению основных прав и свобод человека.

Любое лицо, в отношении которого проводятся специальные розыскные мероприятия, имеет право на получение информации от прокурора или судьи по уголовному преследованию, который разрешил их проведение, после осуществления этих мероприятий, если таковые не повлекли за собой распоряжение о проведении других специальных розыскных мероприятий.

Любое лицо, в отношении которого проводятся специальные розыскные мероприятия, имеет право на возмещение материального и морального ущерба, связанного с нарушением Закона № 59/2012г.

Цели специальной розыскной деятельности состоят из:

а) защита человека (гражданина) от преступных посягательств (его жизни и здоровья, прав и свобод);

б) защита собственности от преступных посягательств;

в) обеспечение безопасности общества и государства (в аспекте защиты от лиц, совершающих преступления).

Направляя специальную розыскную деятельность на достижение социально полезных целей, законодатель особо выделил интересы человека и гражданина (жизнь, здоровье, права и свободы), поставив их на первое место в перечне объектов защиты.

В соответствии со ст. 1 ч.3) Конституции РМ[8] человек, его права и свободы являются высшей ценностью. Признание, соблюдение и защита прав и свобод человека и гражданина — обязанность государства. Защита жизни человека от преступных посягательств с помощью оперативно-розыскных средств и методов наполняет конституционное положение о том, что каждый имеет право на жизнь (см. ч. 1 ст. 24 Конституции), реальным содержанием. Наряду с этим признанные и гарантированные в главе 1 Конституции права и свободы человека и гражданина непосредственно поставлены государством под охрану от преступных посягательств. В частности, таким «охранным» средством является осуществление специальной розыскной деятельностью в необходимых и допустимых законом случаях.

С помощью специальной розыскной деятельностью государство осуществляет охрану собственности (собственность — экономическая категория, отражающая право владения имуществом). Причем в соответствии с ч. 1 ст. 9 Конституции защищаются равным образом частная, и публичная собственность: государственная, муниципальная, и иные формы собственности.

Целью специальной розыскной деятельностью является также обеспечение безопасности общества и государства от преступных посягательств. В соответствии со ст. 1 Закона № 618 от 31.10.1995 «О государственной безопасности» [9] который действовал до 04.10.2025г., под безопасностью понимается защищенность суверенитета, независимости, территориальной целостности и конституционного строя страны, ее экономического, научно-технического и оборонного потенциала, законных прав и свобод личности от разведывательно-подрывной деятельности иностранных спецслужб и организаций, а также от преступных посягательств отдельных групп или лиц. Действующий Закон № 249 от 10.07.2025 г.[11] основывает понятие национальная безопасность по тем же критериям что и предыдущий исключая «от разведывательно-подрывной деятельности иностранных спецслужб и организаций, а также от преступных посягательств отдельных групп или лиц» добавляя: «от внутренних или внешних угроз и опасностей любого характера».

К основным объектам безопасности законодатель относит, в частности, общество (его материальные и духовные ценности) и государство (его конституционный строй, суверенитет и территориальную целостность).

Государство есть основной институт политической системы классового общества, оно осуществляет управление обществом. Его безопасность — это совокупность общественных отношений, которая выражается в защищенности жизненно важных интересов (прежде всего — конституционного строя) основного института политической системы современного общества от внешних и внутренних угроз и позволяет ему функционировать и развиваться. Безопасность государства составляет один из важнейших элементов всей системы безопасности РМ. Под обеспечением безопасности (общества и государства) следует понимать путем определения и реализации государством системы мер экономического, политического, правового, военного, организационного и иного характера, направленных на своевременное выявление, предупреждение и пресечение угроз государственной безопасности.

Исходя из выше сказанного, задачами специальной розыскной деятельности можно считать:

a) выявление преступных посягательств, предупреждение и пресечение преступлений, установление лиц, которые их организуют и/или совершают;

b) раскрытие и расследование преступлений;

c) розыск без вести пропавших лиц или лиц, скрывающихся от органов уголовного преследования или судебной инстанции либо уклоняющихся от исполнения наказаний;

d) выявление имущества, полученного от незаконной деятельности, и сбор доказательств в отношении происхождения этого имущества;

e) сбор информации о возможных событиях и/или действиях, создающих угрозу государственной безопасности.

Следовательно, задачи специальной розыскной деятельности есть определенный этап в достижении цели этой деятельности и одновременно способ такого достижения.

По функциональной направленности задачи специальной розыскной деятельности классифицируют на четыре группы[12]:

- превентивного назначения. В эту группу включены задачи: предупреждение совершения преступлений (общей и частной превенции) и добывание информации о событиях или действиях, создающих угрозу безопасности РМ;

- обнаружения. Здесь известны задачи выявления преступлений и их раскрытия; пресечения. К ним относятся: изъятие предметов, материалов и сообщений при проведении оперативно розыскных мероприятий и прерывание предоставления услуг связи в соответствующих случаях;

- розыска. Известны задачи розыска лица, скрывающегося от органов дознания, следствия и суда, уклоняющегося от уголовного наказания, а также без вести пропавшего.

С учетом рассмотрения задач в системе с целями специальной розыскной деятельности среди первых главенствующее положение занимает группа задач превентивного назначения. Только предупредив совершение общественно опасного деяния, можно «стопроцентно» достигнуть цели специальной розыскной деятельности — защиты соответствующего объекта от преступного посягательства.

Все задачи специальной розыскной деятельности взаимосвязаны и взаимозависимы. Вместе с тем каждая из них автономна, имеет конкретное содержание, обусловленное прежде всего способом решения, влечет определенные юридически значимые последствия.

Функции специальной розыскной деятельности — это отдельные направления специальной розыскной деятельности, различаемые в зависимости от ее конкретных правовых целей. В силу сложности и многогранности специальной розыскной деятельности следует различать отдельные виды соответствующих функций.

Их, в частности, можно разделить на основные и дополнительные. Основные функции:

- предупреждение совершения преступлений, по которым предварительное следствие обязательно;
- обнаружение преступлений;
- розыск лица, совершившего преступление (по факту данного преступления или лица, скрывающегося от органов дознания, следствия или суда либо уклоняющегося от уголовного наказания), а также предметов, сохранивших на себе следы преступления, похищенного имущества и др.;
- содействие уголовному судопроизводству;
- содействие исполнению уголовного наказания.

В специальной розыскной деятельности можно выделить следующие основные направления работы:

а) защита жизни, здоровья, прав и свобод человека и гражданина от преступных посягательств;

б) защита собственности от преступных посягательств;

в) обеспечение безопасности общества и государства (в аспекте защиты от лиц, совершающих преступления).

К дополнительным функциям относятся обеспечение прав, интересов и безопасности участников специальной розыскной деятельности и уголовного судопроизводства, обеспечение специальной розыскной деятельности, оперативно-служебное руководство производством по документационное обеспечение управления, обеспечение безопасности участников уголовного судопроизводства, розыск лиц, без вести пропавших, содействие международным правоохранительным организациям и органам иностранных государств в соответствии с национальным оперативно-розыскным законодательством и международными договорами РМ.

Исходя из выше изложенного совершенствование нормативно-правовой базы, регулирующей специальную следственную деятельность как в рамках уголовного процесса, так и вне его, и ее составляющими являются: - четкое и строгое разграничение специальной следственной деятельности, осуществляемой в рамках уголовного процесса и вне его; - укрепление и наращивание следственных возможностей в рамках уголовного процесса (по уголовным делам) в целях, предусмотренных Уголовно-процессуальным кодексом № 122/2003; - укрепление и наращивание следственных возможностей вне уголовного процесса (по специальным делам) в целях, предусмотренных Законом о специальной следственной деятельности № 59/2012; - регулирование эффективного механизма контроля (авторизации и проверки) специальных следственных мероприятий, назначаемых и проводимых вне уголовного процесса; - устранение недостатков в нормативно-правовой базе, связанных с неконституционностью некоторых нормативных актов.

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MEDICAL SCIENCES

„CUTANEOUS ADNEXAL SQUAMOUS CARCINOMA": MORPHOLOGY OR IMMUNOHISTOCHEMISTRY

Bivolarski I.,
Department of General and Clinical Pathology, Medical Faculty, Medical University, Plovdiv, Bulgaria
Karamphylov G.,
Ermov D.,
Surgical *Department*, MHAT „*Svilengrad"; Town of Svilengrad, Bulgaria*
Baltov M.
Department of Forensic Medicine and Deontology, Medical Faculty, Medical University of Plovdiv, Bulgaria
Shilev P.
Public Health Inspector, Medical College, Medical University of Plovdiv, Bulgaria
DOI: 10.5281/zenodo.21364086

ABSTRACT

Differential diagnosis between classic squamous cell carcinoma originating from the superficial epidermis and a cutaneous adnexal tumor with squamous cell differentiation (so-called "cutaneous adnexal squamous cell carcinoma") is quite possible to make in routine morphological diagnostics. However, in practice, this distinction often requires the use of a panel of immunohistochemical markers. By itself, this additional method does not solve the dilemma in a definitive way, which always requires correlation with the morphological features and architecture of the tumor.

We report a case of an 82-year-old female patient who underwent surgery for right breast cancer 40 years ago. The reason for the current hospitalization was a rapidly growing tumor formation in the right axillary region. Routine biopsy examination of the surgical material showed the presence of carcinoma with squamous differentiation.

A comparison of the morphological features of the potential tumor processes in the case was made, including dormant metastasis from a previous metaplastic carcinoma of the breast, classical and adnexal squamous cell carcinomas. The advantages and weaknesses of the various diagnostic morphological methods are analyzed, as well as the rearrangement of the nosological entities in the Fifth Edition of the WHO Classification of Skin Tumors, according to their molecular-genetic features.

Keywords: skin cancer; cutaneous squamous cell carcinoma; cutaneous adnexal squamous carcinoma, metaplastic breast carcinoma, dormant metastases.

Introduction

Squamous cell carcinoma of the skin originates from epidermal keratinocytes, morphologically presents with different degrees of differentiation and has specific cytological features. The different histological variants are divided into three main groups – low-risk, high-risk and unusual forms. The tumor occurs most often on skin surfaces with intense sun exposure. High-risk anatomical areas are: scalp, ear, lips, nose and eyelids. Precancerous lesions are considered actinic keratosis, burn scars, chronic ulcers, chronic inflammation, human papillomavirus infection, etc. [9]. Clinically, it most often manifests as an erythematous plaque, nodule or ulcer.

Adnexal skin carcinoma with squamous cell differentiation originates from the skin adnexae – follicular, eccrine and apocrine structures and contains more organized structures – ducts, microcysts, follicular elements. It lacks an intermediate zone of dysplasia to the overlying epidermis, which is usually intact. In cases with squamous cell differentiation of adnexal skin carcinoma, keratinization in the center of the tumor nests is of the trichilemmal type [10].

Metaplastic breast carcinoma has over 90% squamous differentiation with varying degrees of keratinization of the classical type. The mandatory criteria for diagnosis are that the tumor must be located in the parenchyma of the mammary gland, not be connected to the overlying skin, and metastases from extramammary primary squamous cell carcinoma (including lung, cervix, head and neck) must be excluded. It is believed that the origin of metaplastic breast carcinoma is a result of pronounced squamous metaplasia, developing in adenocarcinomas, cysts, abscesses, intraductal papillomas, adenofibromas, various chronic inflammatory conditions. In half of the cases, the tumor is associated with cystic formations [5].

Case report

From the anamnesis: An 82-year-old woman was admitted to the surgical department of the Svilengrad Hospital with a painless lump in the right axillary area. The patient reports that 40 years ago, due to established cancer of the right breast, a surgical intervention was performed with the removal of part of the breast. She does not provide additional clarifying information or medical documentation from this period.

Clinical data: An old surgical scar is found in the upper outer quadrant of the right breast. No tumor processes are detected in both mammary glands. In the anterior half of the right axilla there is a nodular formation, measuring 3/4/5 cm, with the appearance of a chronic abscess, painless, without hyperemia. The formation is firmly connected to the skin, but the overlying

epidermis is intact. An incision was made, during which purulent exudate flowed out. On the inner surface of the cystic formation, whitish vegetations with cartilaginous density were found on the wall. Material was taken from these areas for biopsy examination, and part of the purulent exudate was sent for cytological microscopic examination.

Material and metods

The histologic specimens were made with fixation of 10% neutral formalin and embedded in paraffin. The cut sections were 4 mkm thick and stained with hematoxylin and eosin (HE). The exudate from the formation was centrifuged and preparations for cytological examination were prepared from it. The staining was hematoxylin and eosin.

Results

Result of the cytological examination: Among the necrotic materials and hemorrhagic-purulent exudate, single tumor cells with severe degenerative changes were found.

Result of the biopsy examination: (B № 294 – 296 / 2026): The material sent for examination represents a malignant epithelial tumor (carcinoma). Serial sections made from the paraffin blocks revealed that it was a moderately differentiated keratinizing squamous cell carcinoma, most likely of cutaneous adnexal origin, due to the presence of:

• tubular, microcystic and follicular structures (Fig. 1)

• trichilemmal type of keratinization in some of the tumor nests (Fig. 2)

• focal hyalinization in the stroma (Fig. 3)

• absence of a transitional zone with dysplasia to the overlying epidermis

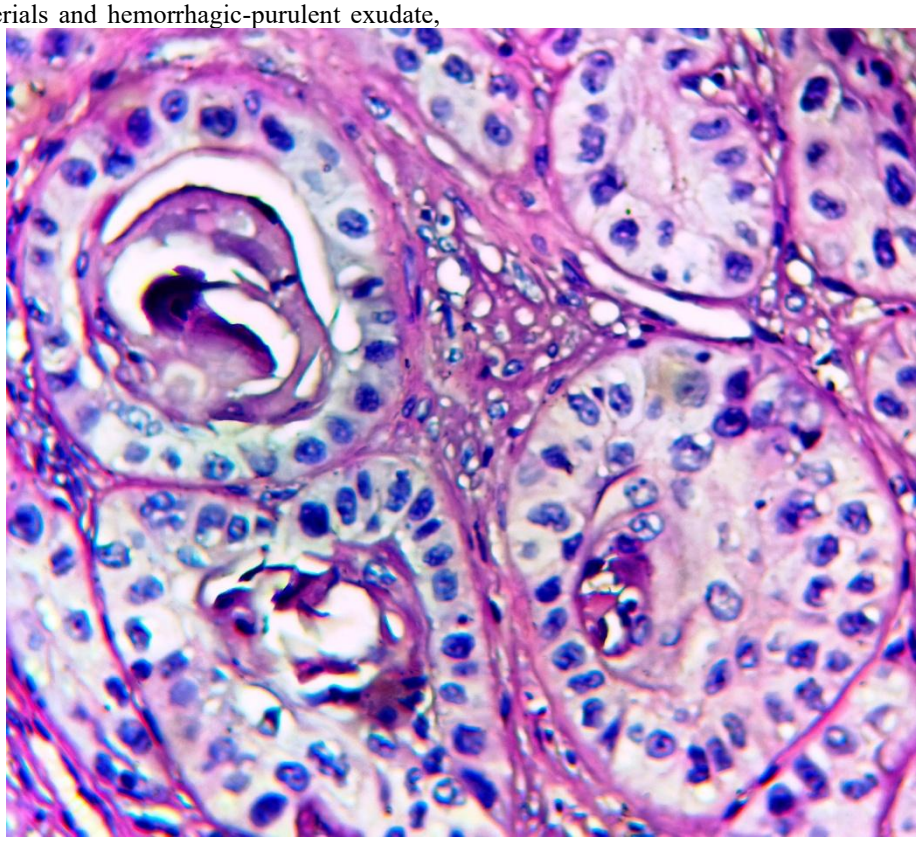

Fig. 1. Cutaneous adnexal squamous cell carcinoma with tubular structures and microcysts filled with keratin pearls of the trichilemmal type - magn.x400.

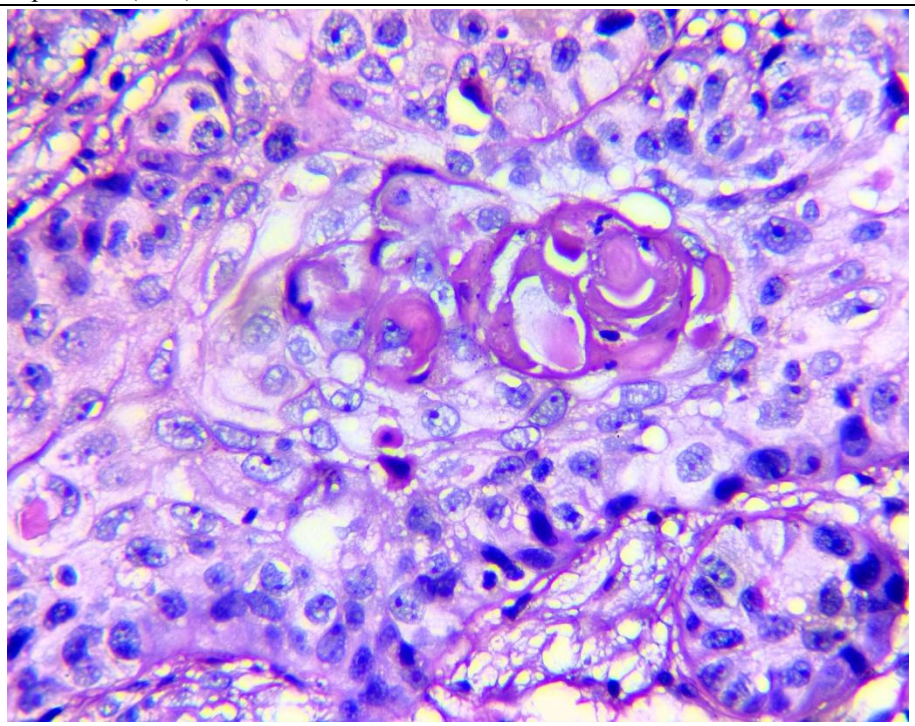

Fig. 2. Nests and tubules of cutaneous adnexal carcinoma with squamous differentiation and trichilemmal-type keratin pearls - magn.x400

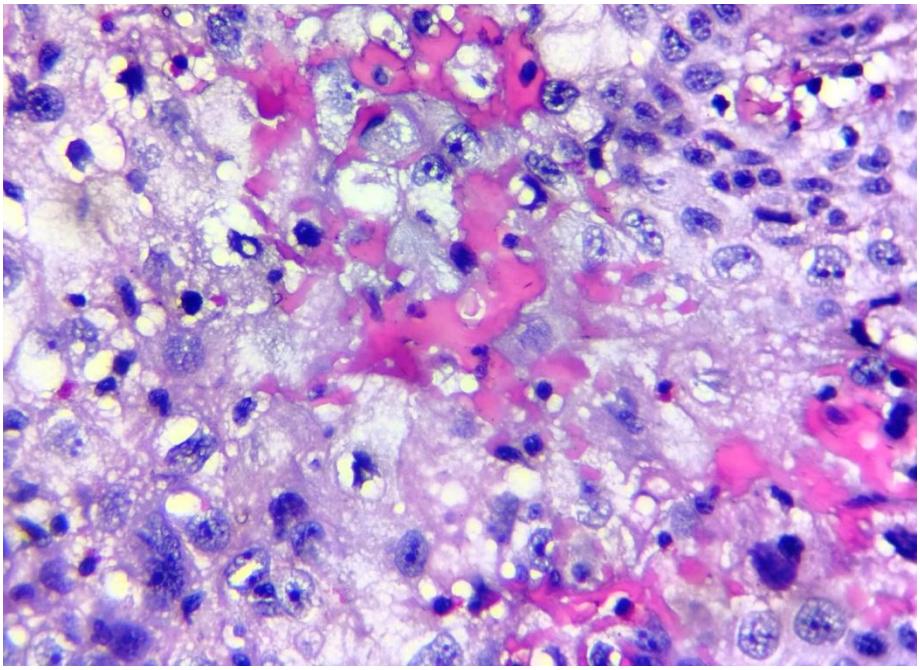

Fig. 3. Cutaneous adnexal squamous cell carcinoma with focal stromal hyalinization - magn.x400

Discussion

Given the patient's history, the diagnostic approach initially focused on ruling out an activated dormant axillary lymph node metastasis from a previous breast cancer. Breast carcinomas have been documented to have the longest period of dormant foci or metastases [7]. Dormant tumor cells (micrometastases) can survive without any symptoms for 25 to 50 years after treatment, after which they can reactivate and grow as a tumor process [1]. The “awakening” of tumor cells remains a mystery, but it is often stimulated by changes in the tumor microenvironment, aging processes, and weakening of the immune system [2].

According to the results of the present biopsy study, only in metaplastic carcinoma breast tumors is differentiation of the neoplastic epithelium into squamous cell carcinoma observed. In this breast carcinoma, over 90% of the tumor parenchyma has squamous cell differentiation with varying degrees of keratinization, but the biopsy material from the axillary zone lacks most of the basic diagnostic criteria for confirming the mammary origin of the malignant tumor: to be localized in the parenchyma of the mammary gland, to have no connection with the overlying skin or skin adnexa, to have typical keratin pearls, and the remaining 10% of the tumor parenchyma to have tubular or glandular structures. For these reasons, the option of

dormant metastasis from metaplastic breast carcinoma is dropped from the differential diagnostic plan.

Table 1.

Comparative morphological criteria between classical and adnexal squamous cell carcinoma.

Tumor / **Criteria**	**Classic SCC**	Cutaneous adnexal **SCC**
Origin	Superficial epidermis /keratinocytes/	Skin adnexae /follicular, eccrine, apocrine structures/
Connections with the epidermis	Clear	Minimal, often absent
Previous lesion	Common actinic keratosis, dysplasia, SCC in situ	Epidermal dysplasia is absent.
Tumor localization	Epidermal with downward infiltration	Dermal with subcutaneous growth
Architecture	Irregularly shaped nests and cords	Organized structures: ducts, microcysts, follicular elements
Keratinization	Typical keratin pearls	Often trichilemmal keratinization
Granular layer	Available	It may be missing
Intercellular bridges	Clearly visible	Weakly expressed
Cytological atypia	Pleomorphic	Monomorphic
Mitoses	Common and atypical	Variable
Stroma	Desmoplasia, variable	Often hyalinized
Perineural invasion	Rarely	Often
Ductal differentiation	Missing	Available
Follicular differentiation	Missing	Available
Presence of mucin	No	Sometimes
Clinical context	UV exposure, adult patients	Slow-growing deep nodule
Pathognomonic morphological criteria	Relationship to the epidermis and typical SCC morphology	No connection to epidermis and adnexal architecture

The differential diagnosis most often includes: trichilemmal carcinoma, squamous cell carcinoma, microcystic adnexal carcinoma, desmoplastic squamous cell carcinoma, infiltrative basal cell carcinoma with squamous cell differentiation. In real diagnostic practice, a panel of immunohistochemical markers is used to distinguish SCC from cutaneous adnexal carcinoma with squamous cell differentiation (Table 2).

Table 2.

Immunohistochemical profile of cutaneous Classical and Adnexal squamous cell carcinomas.

Tumor / **Criteria**	**SCC профил**	Cutaneous adnexal **SCC**
p40	Diffuse +	+ in basal cells
p63	Diffuse +	+ in basal cells
CK5/6	+	+ in basal cells
CK7	−	+ in luminal cells
CEA	−	+
EMA	+	+ Diffuse
BerEP4	−	+/-
GCDFP15/AR	−	+/-

Regarding immunohistochemical differentiation, it should be noted that there is no universal marker to distinguish the two tumors. In the diagnostic immunohistochemical panel, there is a significant overlap of results, which, combined with the inconclusive positive staining, reduces the diagnostic value of immunohistochemistry in this diagnostic dilemma. This is supported by the fact that some cutaneous adnexal carcinomas can mimic classical squamous cell carcinoma almost completely. Some authors recommend identification of ductal differentiation using the markers EMA and CEA. This is not always necessary, because the presence of ductal structures is easily detected by the pathologist even on routine sections stained with HE (Fig. 1).

In the WHO (2022) classification of non-melanocytic skin tumors, squamous cell carcinoma is in the group of keratinocyte/epidermal tumors, and cutaneous adnexal carcinoma (adenocarcinoma, NOS) is in the group of malignant tumors of the skin adnexae with an eccrine and apocrine component [8]. The groups of malignant tumors with follicular and sebaceous differentiation do not include squamous variants. At the same time, the description of the histological characteristics of adnexal squamous cell carcinoma, in addition to the biphasic eccrine and apocrine components, also in-

cludes a population of follicular keratinocytes, as evidenced by the presence of a trichilemmal type of keratinization. This is one of the seven types of keratinization in the hair follicle.

Trichilemmal keratinization was first described by Maurer in 1895 and rediscovered by Holmes (1968) and Pincus (1968) and represents the transformation of the stratified epithelium of the outer root sheath into anucleate homogeneous keratin without an intermediate keratohyaline layer [6]. Trichilemmal keratinization is a specific biological process in which the epithelial cells of the epidermis are abruptly transformed into hard, compact keratin without forming an intermediate granular cell layer. [4].

The fifth edition of the World Health Organization Classification of Tumours (WCT) aims to serve as the basis for global diagnostic standards in tumour pathology. Like other volumes in this series, the Skin Tumours (Skin5) edition follows a standardised approach. Skin5 implements the 'Location-Category-Family-Type-Subtype' taxonomy. Tumours are now classified in a hierarchy reflecting their neoplastic progression and spectrum of aggressiveness. However, this classification principle clearly does not take into account the details of the histological characteristics of the tumour process. The combination of eccrine, apocrine and follicular components does not fit into the subtype 'Cutaneus mixed tumour / chondroid syringoma', because this is benign adnexal tumor of the skin, it has a different specific morphology and is positioned in the group of Apocrine/Eccrine tumours, while hair follicle tumours are a separate group.

In the "Major Updates" section of the 2025 WHO Classification of Skin Tumours, these apparent discrepancies between routine morphology and molecular alterations are not commented on, but sections on adnexal tumour syndromes; new molecular aberrations in nonsyndromic tumours of the cutaneous adnexae; and a new nosological entity: primary adnexal NUT carcinoma [3]. The histological features of NUT carcinoma include a biphasic population of epithelial round luminal and basal cells forming bundles, nests, tubular structures and possibly follicular keratocysts.

The rearrangement of skin tumors identified through the application of molecular techniques and as a result of a deeper understanding of the genetic landscape, without searching for and indicating clear correlations with the criteria of routine histological diagnosis, is a prerequisite for diagnostic collisions, especially in pathohistological laboratories with the impossibility of molecular genetic studies.

Conclusions

1. In distinguishing classic squamous cell carcinoma from cutaneous adnexal carcinoma with squamous cell differentiation, routine morphology plays a leading role and not immunohistochemical examination.

2. In practice, an integrative approach is needed and a search for clear correlations between routine histological diagnostic criteria and molecular - genetic tumor characteristics is needed.

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STUDY OF ATTITUDES AND MOTIVES OF PATIENTS WHEN CHOOSING SPECIALIZED ORTHOPEDICAL CARE

Gonovski K.,
Doctoral candidate in the Department of Health Management and Health Economics, Faculty of Public Health „Prof. Tzecomir Vodenitcharov, MD, DSc", Medical University – Sofia
Petrova-Gotova Ts.,
Professor in the Department of Health Technology Assessment, Faculty of Public Health „Prof. Tzecomir Vodenitcharov, MD, DSc", Medical University – Sofia
Naseva E.,
Assoc. Professor in the Department of Health Management and Health Economics, Faculty of Public Health „Prof. Tzecomir Vodenitcharov, MD, DSc", Medical University – Sofia
Valkanov S.,
Chief Assistant in the Department of Urology and General Medicine, Faculty of Medicine, Medical University – Plovdiv
Penev L.
Doctoral candidate in the Department of Health Management and Health Economics, Faculty of Public Health „Prof. Tzecomir Vodenitcharov, MD, DSc", Medical University – Sofia
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ABSTRACT

Musculoskeletal disorders are among the most frequent professional work-related injuries. This article explores, analyzes and systematizes the attitudes and leading motives of patients with musculoskeletal disorders when choosing the Ward of Orthopedics and Traumatology at „Pulmed" University Hospital for their treatment.

In order to reduce the risk of MSDs and their chronicity, systematic prevention for workers is necessary throughout their entire working life.

Keywords: musculoskeletal disorders, patients, motives, choice, hospital.

Introduction

Musculoskeletal disorders are (MSDs) among the most frequent professional work-related injuries. Every fourth citizen of the European population suffers from chronic musculoskeletal disorders.

According to data from the European Agency for Safety and Health at Work (EU-OSHA, 2019), approximately 60% of all workers, who report work-related health problems, cite musculoskeletal disorders as the most common cause of health impairment. This is mainly due to recent trends in the labour market, namely - digitalization, the increasing use of computers and the reduction of physical labour.

The work-related musculoskeletal disorders have significant economic consequences and losses for society, and in some EU member-states they go up to 2% of the gross domestic product. Additionally, they negatively affect people's quality of life and lead to huge costs (direct and indirect) borne by workers, employers, the healthcare system, the economy and society as a whole [1; 2]. The direct costs include resources used for healthcare (diagnostics and treatment of diseases, rehabilitation costs), medicinal products, costs for workers' indemnity, etc. The indirect costs are related to absenteeism, disruption of work processes within the teams, productivity decline, production delays and substitution of ill workers (including, training for the new employees). It is considered that these indirect costs are several times higher than the direct costs of the enterprises.

From 2020 to 2022, the European Agency for Safety and Health at Work (EU-OSHA) is running a awareness-raising campaign on work-related MSDs and the importance of preventing them. The main priority is to promote the collaboration of employers and other stakeholders in order to prevent MSDs and enhance good musculoskeletal health among workers [1; 2].

The **purpose** of this article is to research, analyze and systematize the attitudes and leading motives of patients with musculoskeletal disorders when choosing the Ward of Orthopedics and Traumatology at „Pulmed" University Hospital for their treatment.

To achieve this objective, we have set the following **tasks**:

- Research the social and demographic profile of patients who looked for cares in the ward.
- Analyze patients' leading motives when choosing the Ward of Orthopedics and Traumatology of University Multi-Profile Hospital for Active Treatment „Pulmed".
- Analyze the ratio between the emergency and elective admission of patients in the ward and its impact on the motives when choosing the healthcare institution.

Material and methods of the research: In processing the data and analyzing the results, a documentary method was used - scientific publications on the problem in national and international literary sources

were studied, as well as official data, reports and documents of hospital medical institutions, data from the National Statistical Institute, National Center of Public Health and Analyses, Ministry of Health, WHO and the European Agency for Safety and Health at Work; a sociological method - an anonymous survey was conducted and graphical analysis was applied.

The statistical methods used are descriptive and analytical. Categorical variables are presented as absolute (n) and/or relative frequencies (%), with the proportion of individuals who did not answer a given question being ignored when determining relative frequencies. Quantitative variables, depending on the shape of their distribution, such as those with a Gaussian distribution, are represented with an arithmetic mean (m) and standard deviation (sd), and those with a different distribution with a median (me) and interquartile range (IQR: 25th and 75th percentiles). The shape of the distribution was assessed with the Kolmogorov-Smirnov (with Lillefors correction) or Shapiro-Wilk tests. Quantitative variables in two groups were compared with Student-Fisher t-test or Mann-Whitney test, depending on the distribution of the variables.

Relationships between categorical variables were assessed with Chi-square analysis (Fisher's exact test when applicable). Results with $p<0.05$ are considered significant. The analysis was performed with IBM SPSS version 29.

Results and discussion

The study was conducted among 445 patients in the Ward of Orthopedics and Traumatology of „Pulmed“ University Hospital – Plovdiv, Bulgaria in the period January - May 2025. Of the participants in the survey, just over half (56.9%) were women, while the remaining 43.1% were men. The mean age of the respondents was 61.4 years (SD = 11.8 years), which was similar for both sexes (p=0.360). Depending on their place of residence, the participants were divided into two nearly equal groups: 42.4% were from Plovdiv, and 41.3% were from another city. The remaining 16.3% lived in a village.

Almost half the surveyed persons (46.7%) have graduated secondary education, every third (35.5%) has higher education and 17.5% have primary education. One participant (0.2%) is illiterate. Both sexes differ significantly in view of education and women are much better educated (p=0.030), whereas for the purposes of the present analysis the only participant with no completed educational degree was excluded due to low frequency.

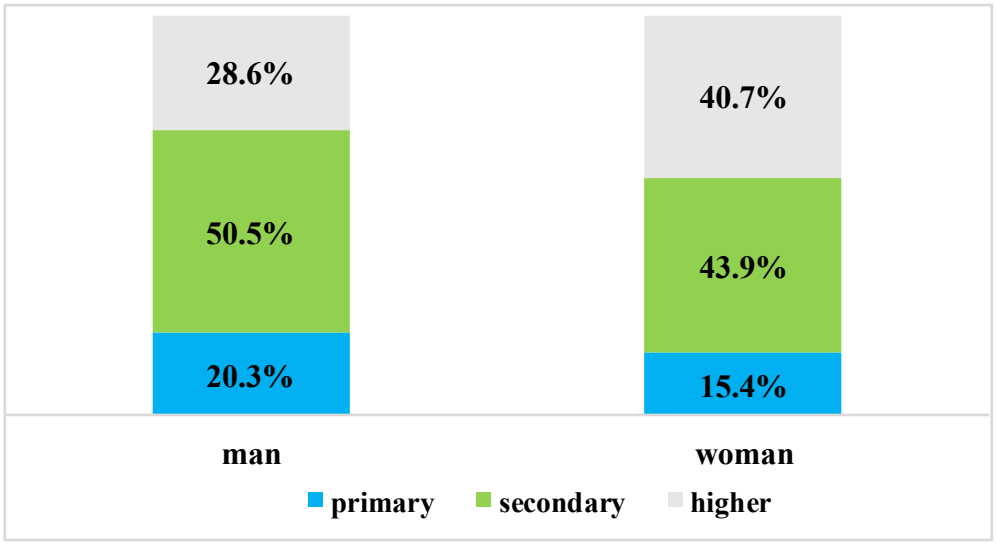

Figure 1. Distribution of patients by education and gender

Over half of the respondents (51.7%) indicated that they chose the hospital, because of a particular specialist; other 23.6% were referred by a doctor; eight patients (1.8%) went there because of two reasons – because of particular specialist and they were referred by a doctor; in 19.1% of the cases the hospital was recommended by relatives or friends and only 3.6% got in „Pulmed“ by chance and one participant (0.2%) chose this hospital, because of its proximity to his home or family.

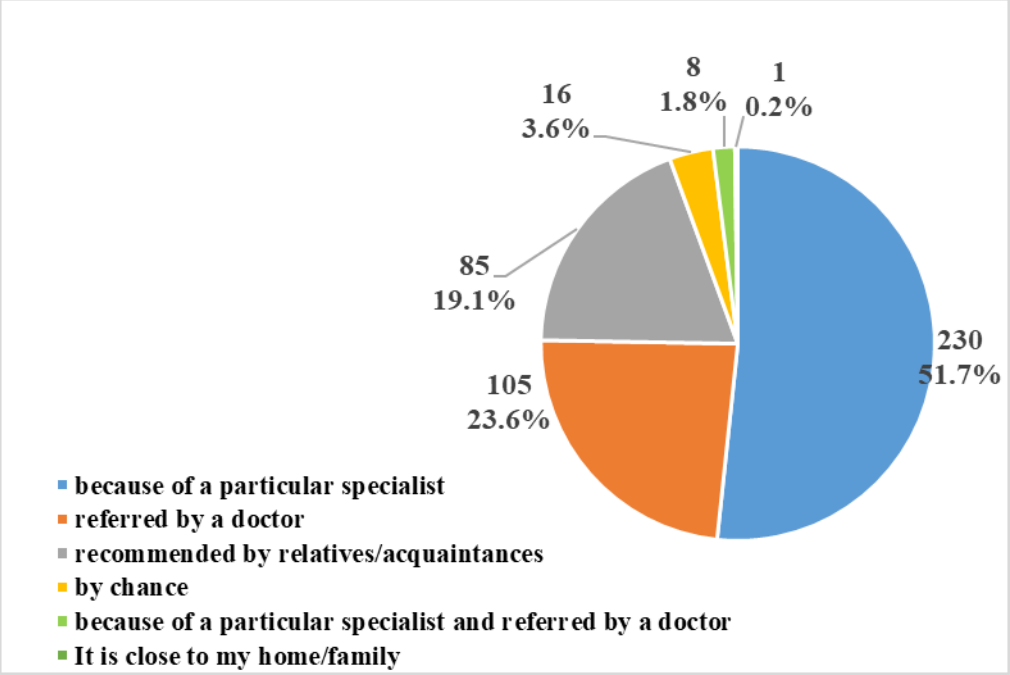

Figure 2. Main reasons for choosing „Pulmed“ Hospital

We established significant differences among the motives for choosing the hospital in view of participants' residence ($p<0.001$). The motive „particular specialist" is valid to a similar degree when it comes to Plovdiv and the other towns (56.8-59%), yet it was not that commonly mentioned by those, who live in villages (19.4%). On the other hand, the persons, who live in villages are much more often referred by a doctor or relatives/friends compared to the ones, who live in Plovdiv and the other towns. The accidental reception in the hospital is also more common among those who live in a village. It is noteworthy that the responses of Plovdiv residents are similar to those from other cities.

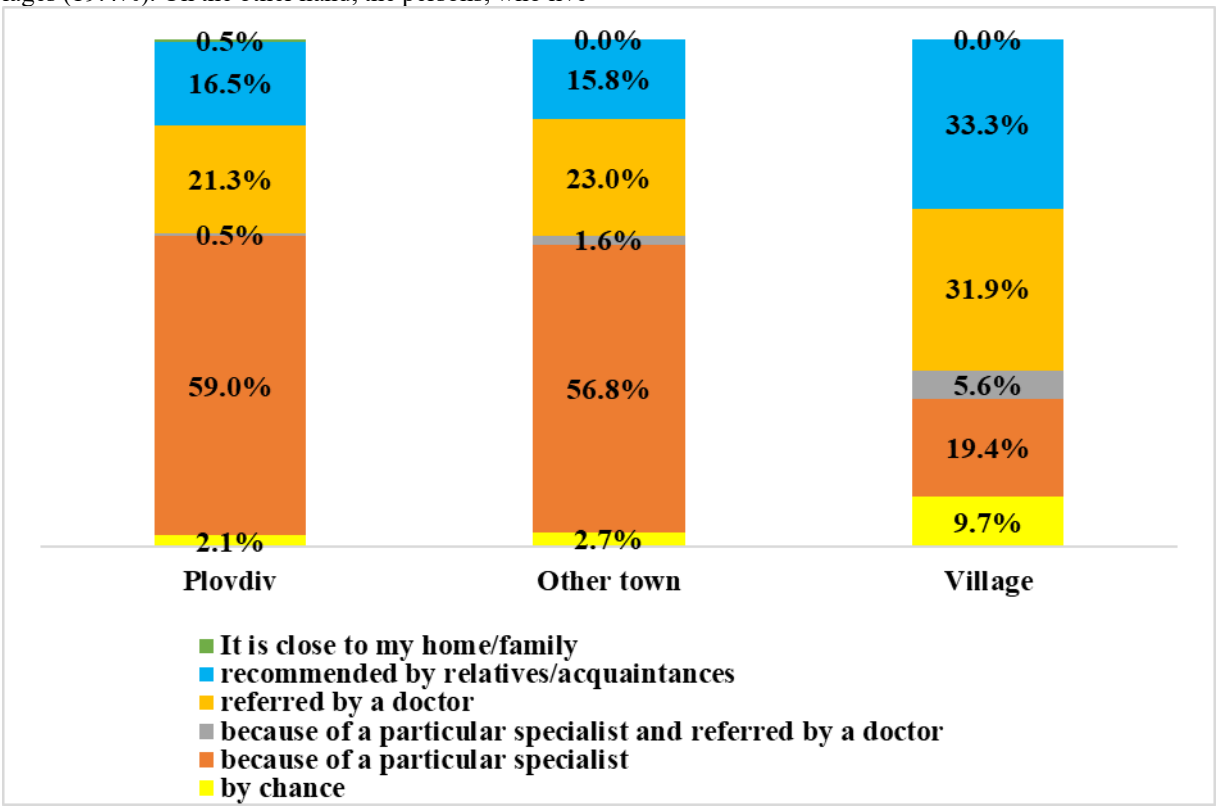

Figure 3. Reasons for choosing „Pulmed“ Hospital according to location

The data analysis concerning the nature of hospitalization demonstrates significant prevalence of the scheduled reception (86.1% of patients) and only 13.9% were received in the state of emergency. This ratio proves that University Multi-Profile Hospital for Active Treatment „Pulmed" is perceived by the patients as purposeful choice for scheduled treatment, not just as the closest place for emergency cares.

The high rate of schedule reception (over 5/6 of the sample) demonstrates that most patients had the time and opportunity to make an informed and conscious choice of healthcare institution. This confirms the high reputation of the Orthopedics and Traumatology Ward of „Pulmed“ as a preferred center for specialized, high-tech and elective medical care, where patients deliberately seek out specific specialists or facilities.

We have proven significant difference in the manner of receiving the patients, depending on their residence (p=0.030). The highest share of those who were received urgently live in the villages (20.8%), followed by the inhabitants of Plovdiv (16%), whereas this is rarest among the ones who live in other towns (9.3%).

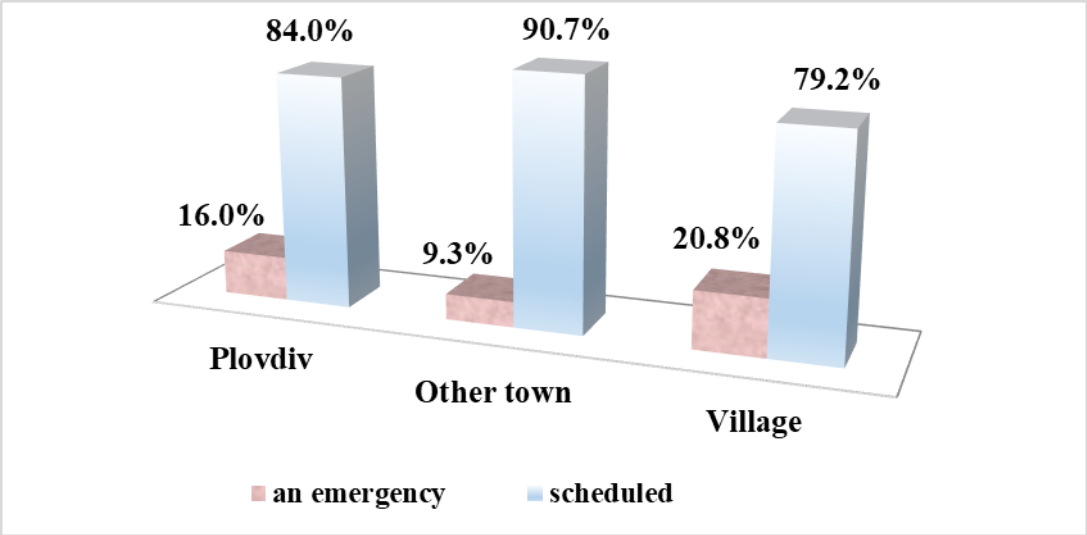

Figure 4. Percentage of hospitalized patients by place of residence

We established there is connection between the manner of reception (scheduled or emergency) and the motives behind choosing this ward (p<0.001). In the case of the scheduled reception vast majority of patients (71.6%) chose „Pulmed“, because of particular specialist compared to the emergency reception (32.7%). On the other hand, among the patients received, because of emergency more than one-fourth (27.3%) have chosen the hospital by accident, whereas in the case of the scheduled reception they are only 0.3% (just one patient). In addition, to the ones who were received, because of emergency, 40% were referred by a doctor, whereas this is in effect for just 28% of the patients received according to schedule. For the analysis purposes the answers of low frequency have been neglected („recommended by relatives/acquaintances”, „it is close to my home/family”, simultaneous choice of „because of particular specialist” and „I was referred by a doctor”).

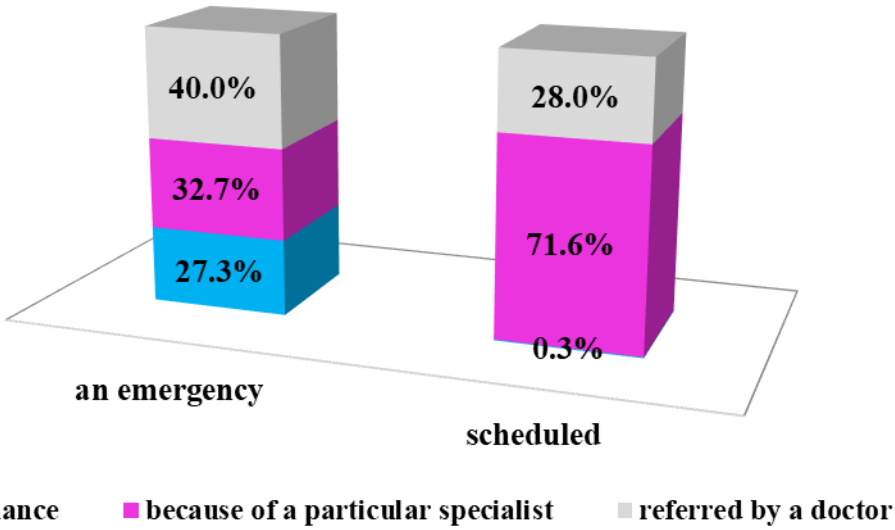

Figure 5. Association between type of admission (emergency vs. elective) and motives for choosing the hospital

Almost all (98.2%) were admitted to „Pulmed“ for surgical treatment, 0.9% for treatment with no surgical intervention, 0.7% because of emergency, without specifying the procedure and in the case of one patient (0.2%) it was because of diagnostic procedure.

Only one patient answered that he needs to visit such ward once weekly or more often; for 12.3% this is

necessary approximately once monthly, whereas for the majority (87.5%) this happens several times a year or less often.

The disease of participants requires work absenteeism with median annual duration of 20 days (IQR 15-25), whereas it varies from 1 to 42 days. It is worth mentioning that most of the inquired persons didn't answer this question, because of the fact that they do not work or they do not have to be absent from work (which is evident from the average age).

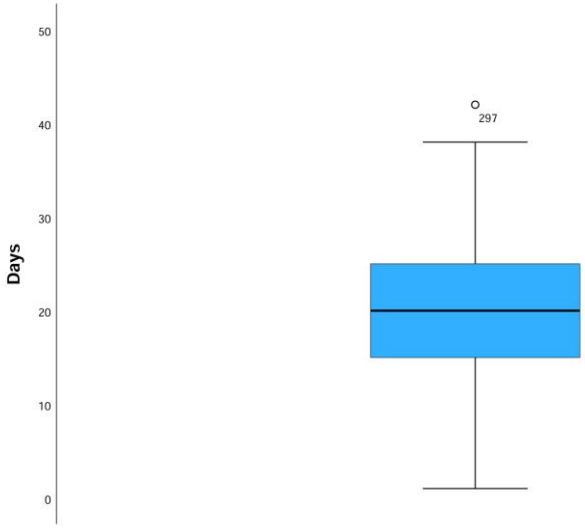

Figure 6. Distribution of the number of days absent from work on an annual basis

The MSDs cover wide range of degenerative and inflammatory conditions impacting muscles, joints, tendons, ligaments and nerves, most often in the area of the back, neck, shoulders and upper limbs and because of this reason they are the most common healthcare work-related problem in the European Union [3].

Conclusion

The analysis results demonstrate numerical prevalence of the scheduled hospitalizations compared to the emergency reception. This statistics proves that people choose the Ward of Orthopedics and Traumatology of University Hospital „Pulmed" purposefully as a specialised institution for diseases, related to the musculoskeletal system.

Musculoskeletal disorders are among the most common reasons for long absenteeism from work and premature retirement, because of medical reasons. In order to reduce the risk of these diseases and their chronicity, systematic prevention for workers is necessary throughout their entire working life.

The healthy work environment is a key factor for the social responsibility of every business and not only provides competitive advantages, but also reduces the costs, related to permanent disorders of the musculoskeletal system borne by the healthcare system and society.

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PEDAGOGICAL SCIENCES

THE ROLE OF PROBLEM-BASED LEARNING IN THE DEVELOPMENT OF COGNITIVE SKILLS IN PHYSICS LESSONS IN NATURE-ORIENTED CLASSES

Jalilova S.
Doctor of Philosophy in Pedagogy, Associate professor
Hasanova I.
Master's student
Azerbaijan State Pedagogical University
DOI: 10.5281/zenodo.21364109

ABSTRACT

The program for modernizing educational content covers all aspects of the educational process. By promoting the competency-based approach in education as a fundamental idea, it encourages educators to seek and test new technological approaches aimed at developing students' key competencies. The purpose of the study is to determine the relationship between students' problem-solving skills in physics and their level of awareness of physics-related problems in nature-oriented classes.

Keywords: problem-based learning, student, physics, learning process, cognitive skills.

Introduction

The rapid development in science and technology in recent times has made the restructuring of the education system necessary. This situation has brought to the forefront the need to educate students who possess problem-solving skills, can connect their thinking with the knowledge they acquire, and are able to accept and apply innovations. Our society's labor market needs well-trained professionals with skills such as problem-solving, critical thinking, collaboration, communication, and manipulation to meet new demands. The problem-based learning approach encourages engagement by using real-life situations as problems, prompting students to actively participate in the learning process rather than simply relying on information provided by the teacher.

In modern teaching, one of the main goals is for students not only to acquire theoretical knowledge but also to apply it, solve problems, and identify cause-and-effect relationships. Today, when we think of science and technology, one of the first scientific fields that comes to mind is physics. Physics seeks to discover phenomena in the world and the universe that have not yet been fully understood, and it constantly presents people with various situations. Because such situations encourage people to think scientifically and conduct research, the field of physics holds an important place in our lives.

In nature-oriented classes, the subject of physics plays a key role in developing students' scientific worldview, logical thinking, and research skills. To be competent means to be able to mobilize existing knowledge and experience in a given situation. In modern teaching, one of the main goals is not only for students to acquire theoretical knowledge but also to apply it, solve problems, and identify cause-and-effect relationships. In this regard, problem-based learning is one of the effective pedagogical approaches for developing cognitive skills in physics lessons.

Problem-based learning is based on the theoretical principles of the American philosopher and educator John Dewey (1859–1952), who in 1894 founded an experimental school in Chicago that replaced the curriculum with activities of play and work. According to Dewey, there are four instincts that play an important role in learning: social, constructive, artistic expression, and research. J. Dewey's conceptual principles are as follows:

- The student assimilates the material as an active participant in their own learning.
- problematizing the educational material;
- student activity;
- the relevance of learning to the student's life.

Problem-based learning is an instructional approach based on creating students' interest and intrinsic motivation for learning. In this approach, the instructional material is presented not as ready-made knowledge, but as a system of problematic situations. Using problem-based learning methods in physics lessons allows students to investigate physical phenomena, identify cause-and-effect relationships, and connect the knowledge they acquire to real life. As a result, this method both helps solve certain educational problems and ensures the development of the following cognitive skills in students:

- **Analysis skill -** As the student investigates the problem situation, they identify its main causes tries to identify the main causes of a problematic situation.
- **Comparison skill -** The student compares different situations, identifying the similarities and differences aspects.
- **Ability to formulate hypotheses -** The student proposes possible solutions to the problem. This, develops his creative and scientific thinking skills.
- **Drawing conclusions -** After experiments and observations, the student **draws** conclusions from the data obtained.
- **Application skill -** The student applies the physical law they have learned to a phenomenon in everyday life.

Problem-based learning is a type of developmental instruction in which students' systematic independent inquiry is combined with the assimilation of established scientific findings. In this instruction, the system of

methods is structured with consideration for the principles of purposefulness and problem-orientation. Solving problem-based questions requires explaining a specific physical phenomenon or predicting how it will occur under certain conditions (without performing calculations). Typically, such problems do not involve numerical data. The absence of calculations allows students to focus their attention on the physical nature of the phenomenon. Solving problem-based questions helps develop students' attention, observational skills, and graph literacy. It also aims to stimulate students' thinking, develop their creativity, and increase their cognitive interest. In problem-based learning, teachers encourage students to formulate problems independently, which develops their creativity, as problem formulation is a fundamental stage of any creative act.

In problem-based learning, questions can be part of the structure of a problem-based task, embodying the function of a student who creates the problem. This learning method is also an active teaching approach that involves presenting students with real-world problem situations.

In physics classes for science-oriented students, solving problem-solving questions requires explaining a specific physical phenomenon or predicting how it will occur under certain conditions. The essence of the explanatory-problem method of instructional material is that the teacher not only organizes the transmission of information but also engages students in the search for a solution to a particular problem. The teacher demonstrates the cognitive conflicts that arise at various stages of the problem-solving process. Cognitive skills are the abilities related to a student's reception, understanding, analysis, comparison, drawing conclusions, and application of information in new situations. Physics is a favorable subject for the development of these skills, as the study of physical phenomena requires observation, measurement, experimentation, and logical thinking. In other words, the teacher poses the problem, solves it, and thus demonstrates scientific thinking. Students, in turn, observe the correctness and logic of this process and learn the steps for solving the problem.

In the process of teaching physics, such problems can be based on phenomena encountered in daily life. For example, "Why does a sharp knife cut better than a dull one?", "Why does a very heavy ship float on water, but a small nail sinks when dropped into it?", "Why can a skier move on snow without sinking?", "Why does a passenger move forward when a car brakes suddenly? " questions like these spark students' interest in scientific thinking. In science-oriented classes, students may go on to pursue careers in fields such as technology, engineering, medicine, biology, chemistry, and other natural sciences. Therefore, in these classes, it is not enough for physics lessons to be based solely on theoretical explanation. Students must understand the essence of physical concepts, relate them to experience, and be able to use them to solve real-world problems.

In this article, we will provide an example lesson based on the main stages of a problem-based lesson.

Grade: 8th Grade

Subject: Physics

Topic: Section III. Pressure. 3.3. Archimedes' Force

Teaching method: Problem-based learning

Key concepts: Force, volume, surface area, pressure.

Problem situation:

The teacher shows the students a "ship" made of a small nail and foil, filled with water.

Teacher: Why does a very heavy ship float on water, but a small nail sinks when it falls into water?

Explanation:

Although a ship is very heavy, its hull has a large volume and contains air pockets. For this reason, the ship's overall density is less than the density of water. When the ship enters the water, it displaces an amount of water equal to its volume, and that water pushes the ship upward. This force is called the Archimedes' principle. If the Archimedes' principle balances the weight of the ship, the ship does not sink and floats. A nail, however, has a small volume and, because it is made of iron, its density is greater than the density of water. It displaces a small amount of water, so the Archimedes force acting on it is less than its weight, and the nail sinks.

The question piques students' interest and prompts them to think. Students make various predictions based on their prior knowledge.

Formulating Hypotheses:

Students:

1 - The ship stays on top of the water because it is large, while the nail sinks because it is small and heavy.

2 - Maybe the shape of the ship helps it float. Because the ship spreads out over the water, while the nail, being thin and small, pushes the water away less.

3 - The nail is made of iron, so its density is greater than that of water. That is why the nail sinks.

4 - Whether an object floats does not depend solely on it being heavy or light. The shape, volume, and how much water it displaces also play a key role.

5 - When a ship enters the water, an upward force acts on it. This force keeps the ship from sinking because it balances the ship's weight.

Experiment:

The foil is first dropped into the water in a ball shape and its sinking is observed. Then, the foil is shaped into a boat and is tested to see if it will float on the water.

Conclusion:

Students understand that an object's buoyancy does not depend solely on its weight. Here, the object's density, volume, shape, and the amount of water it displaces play a key role. This example is very suitable for problem-based learning, as students are not memorizing a ready-made rule, but are trying to explain Archimedes' principle for themselves, starting from a real-life phenomenon.

There are many examples considered appropriate for the use of the problem-based explanatory method across all grades in the teaching of physics in nature-oriented classes. Thus, the uniqueness of the problem-based explanatory method is that students do not just passively receive information. They attempt to predict the next step after observing the teacher's explanations,

reasoning, or demonstration experiments to verify the validity of the hypotheses. Thus, students first observe the teacher's activity, and then gradually join in and participate together. As the students progress, the level of their participation in this process also gradually increases.

In our study, we can conclude that problem-based learning is an effective teaching method that positively impacts the development of students' cognitive skills in physics lessons. This method moves students from the position of passive listeners, guiding them to actively think, investigate, and draw conclusions. The application of problem-based learning in science-oriented classes allows students to gain a deeper understanding of physical phenomena, connect theoretical knowledge with practical situations, and develop critical thinking skills.

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THE EFFECT OF FEAR OF FAILURE IN SCHOOL ON LEARNING MOTIVATION

Qaragozova V.
Sheki branch of Azerbaijan State Pedaqogikal University
Teacher of the Departament of General Sciences
Azerbsaijan, Sheki
ORCID ID: 0009-0003-8072-8009
DOI: 10.5281/zenodo.21364128

ABSTRACT

In modern times, learning motivation is considered one of the most pressing problems of educational psychology. Motivation, in addition to being the main driving force of human activity, is an important factor determining the activity, perseverance and academic achievements of pupils and students in the learning process. Studies show that highly motivated learners approach educational activities more responsibly, show interest in acquiring new knowledge and are more persistent in solving the difficulties they encounter.

Internal interests, teacher-student relationships, family support, emotional environment and modern educational technologies play an important role in the formation of learning motivation. In particular, the teacher's supportive and trust-based attitude, individual approach and interesting organization of learning increase the motivation of students. Studies confirm that there is a positive relationship between motivation and academic achievements. Also, the use of computer and Internet technologies creates a favorable educational environment for learners and increases their interest in learning.

Emotions also play an important role in the development of motivation. Positive emotions strengthen interest in learning and self-confidence, and in some cases, negative emotions can also play the role of an additional stimulus. Therefore, taking into account the individual characteristics of each student in the educational process, creating a motivating environment and applying modern teaching methods make a significant contribution to improving the quality of education.

Keywords: learning motivation, academic achievement, intrinsic motivation, student motivation, educational activity, teacher-student relationships, emotional factors, learning effectiveness.

Entry

In the modern era, the problem of motivation is considered one of the most relevant research directions in psychology. The study of this area allows us to more deeply understand the essence of human behavior, the reasons for activity and the mechanisms that guide the actions of the individual. The study of motivation, especially in the field of education, is of great importance in terms of determining how learners are involved in the learning process. Since educational activity covers a long stage of human life, the study of learning motivation also contributes to the explanation of activity motivation in general. However, despite the theoretical importance of the field of motivation, its practical application is still not sufficiently developed. According to Heckause (2003), there is almost no other psychological field that can be studied from as many different directions as the psychology of motivation.

The relevance of the problem of motivation is also due to the fact that the issue of improving the quality of education has not been fully resolved. Despite the innovations and standard changes in the education system, in many cases students' interest in learning decreases. This leads to a weakening of academic performance and a decrease in the general level of education. This situation can be explained by the fact that educational activities have a different meaning and importance for each person. Studying the interests of young people and building a motivation system based on these interests can create conditions for improving educational outcomes. This is also confirmed by the fact that academic success and failure are closely related to the personal characteristics and motivation level of students.

From a psychological point of view, needs are the main driving force of human activity. Depending on the level of perception of the need, it can manifest itself in the form of desire or inclination. In order for a person to transform a need into a desire, it is important for him to consciously accept and evaluate it. In this regard, desire is active in nature and pushes the individual to certain activities. Consciously perceived needs become a feature of the personality, not just the organism.

Motives are the basis of human activity, and motivation plays an important role in achieving success in the learning process. Strengthening motives in learning activities allows for determining directions of activity and predicting results. In particular, the development of internal motives increases the efficiency of the learning process. Therefore, the student's personal interest and internal motivation to acquire knowledge are considered the main driving force of educational activities.

One of the main tasks of educational institutions is to create an environment for learners in which they can independently solve educational problems, make the right decisions, and acquire the necessary knowledge, skills, and habits in this process. The knowledge gained as a result of independent activity becomes more solid and systematic. As the student observes the results of his/her own activities, his/her self-confidence increases and he/she gains additional motivation for future successes. Therefore, both in-class and out-of-class activities and informal communication play an important role in the formation of motivation. A positive psychological environment creates conditions for improving the attitude of students to the school, the teacher and the subjects taught.

In order to maintain motivation throughout the training process, a number of factors should be taken into account when preparing and presenting educational materials. The volume of new information should correspond to the age characteristics of the learners, be linked to previous knowledge and be presented in a way that arouses interest. The teacher's speech should be clear and attractive, as well as the inclusion of practical activities in the teaching process, which helps to increase motivation.

In modern schools, the development of motivation is mainly based on the formation of the achievement motive. For this purpose, special educational programs are developed that take into account the degree of difficulty of tasks, the duration of their implementation and other components. At the same time, a style of interaction between the teacher and the student based on cooperation is applied. In modern conditions, where information sources are multiplying, one of the main tasks of teachers is to teach students how to use these resources correctly. Therefore, such types of activities as using electronic textbooks, preparing presentations, computer-based tests and working with Internet resources are widely used.

To understand the essence of the concept of motivation, it is necessary to pay attention to the content of the terms motive and motivation. There is no single position in the psychological literature regarding the explanation of these concepts, and in many cases they are used in the same context. According to E.P. Ilyin, motivation expresses the process of formation of a motive, and a motive is a complex psychological structure that directs human behavior and activity. Learning motivation is considered a special type of motivation that is an integral part of learning activity and directs the student's activity to certain aspects of learning.

In general, motivation is characterized as an internal force or desire that prompts a person to act to achieve a certain goal. It directs a person's behavior, helps him to strive to achieve the goal, demonstrate perseverance and increase the efficiency of activity. Studies show that motivated students are more responsible for their education, show interest in learning, and exhibit a positive attitude. Otherwise, even if the teacher is highly professional, the effectiveness of the teaching process may decrease.

The ability to self-motivate plays an important role in a person’s success. This characteristic determines an individual’s attitude to activity, perseverance, and level of achievement. According to Garcia and Pintrich’s (2018) approach, learning motivation consists of three main components: understanding the purpose of the activity, belief in one’s own capabilities to achieve that goal, and emotional satisfaction obtained as a result of the activity.

Research distinguishes two main forms of motivation: intrinsic and extrinsic motivation. Intrinsic motivation is related to interest and enjoyment derived from the activity itself. Extrinsic motivation is related to rewards, grades, or other benefits that will be obtained as a result of the activity. Motivation plays a decisive role in shaping the attitude towards learning. When the level of motivation is high, students do not shy away from difficult tasks, put more effort into solving problems, and develop critical thinking skills.

Motivated learners approach the learning process creatively, come up with new ideas. They seek out and enjoy exploring the problems they encounter. They ask deeper questions, are able to apply information to new situations, and demonstrate the ability to use the knowledge they have acquired in a variety of settings. These characteristics also have a positive impact on their academic achievement.

Studies on the factors that determine academic success have mainly focused on the motivational characteristics of students. Some studies have specifically studied the motivation of students belonging to minority groups. For example, in Germany, although the indigenous population constitutes a small part of the general population, it is more affected by various social and educational problems. In this regard, studying the motivational characteristics of different social and ethnic groups allows for a more efficient organization of the educational process.

A number of studies have shown that educational opportunities and motivation levels differ between different social and cultural groups. Some minority groups living in Germany are still excluded from the mainstream cultural environment of society, have limited access to social services, and face certain difficulties in the field of education. For this reason, a comparative study of the motivational levels and academic achievements of students from different cultural environments is of particular importance. The interaction between motivation and educational achievements is considered one of the main components of the learning process.

In scientific research, student motivation is considered one of the main factors affecting educational success. The motivational level of students directly affects the quality of their academic performance. Students with a lack of motivation usually face various difficulties in the educational process. In this regard, one of the main tasks of teachers is to increase students' interest in learning and ensure their active participation. Motivation plays an important role at all stages of the educational process and strengthens students' desire to participate in both classroom and extracurricular activities.

Highly motivated students believe in their abilities more, approach the learning process responsibly, and demonstrate activity in acquiring new knowledge. Therefore, teachers should support students using various teaching methods, explain the importance of scientific knowledge and its connection with future professional prospects. Motivated students approach educational activities carefully, demonstrate a positive mindset, and strive for continuous learning.

Creating a healthy competitive environment in educational institutions also serves to increase motivation. The results of the conducted studies confirm that there is a positive relationship between motivation and academic achievement. Motivation affects students' cognitive activity, shapes their goal-oriented behavior, increases their efforts, and creates conditions for them to demonstrate initiative and perseverance. Therefore,

motivation is considered one of the important psychological factors influencing student development at school.

Patrinos and Psacharopoulos (2018) investigated the attitudes of secondary school students towards physics and the impact of motivation on learning outcomes. The results of the study showed that motivation plays an important role in the mastery of physics and that highly motivated students achieve more successful results by putting in more effort.

A study conducted by Peng (2020) aimed to determine the relationship between motivation, educational experience and satisfaction level. The results showed that students show high interest in learning in an online educational environment and accept that internet-based programs create successful learning opportunities. However, studying exclusively in an online environment does not always create high motivation. The main reasons for this were the limited opportunities for live communication and the high demand for self-control. The study emphasizes that the technical and methodological support of teachers and software developers has a significant impact on the motivation and satisfaction level of students.

Tsymbal's (2018) study highlighted the importance of motivation in foreign language learning. The study found that interest, enjoyment, and additional motivation play an important role in learners' second language acquisition. A study involving 80 students found that teacher factors, personal mindsets, and parental support had a significant impact on motivation to learn a foreign language.

Zee, Koomen, and Van der Veen (2019) examined the relationship between teacher-student relationships and academic motivation. The study found that factors such as caring attitudes, support, trust, friendship, and high expectations increased students' motivation. Teachers' sincere attitudes and continuous support positively affected students' interest in learning.

A study conducted in Indonesia by Tanduklangi and Lio (2019) examined the effects of motivation and mindset on English language achievement. The results revealed that motivation had a positive and statistically significant impact on academic performance.

Chetri (2017) investigated the impact of motivation on educational outcomes with the participation of 480 secondary school graduates. According to the results of the study, motivation is one of the main factors that ensure the continuity of the educational process and increase academic achievements. The author recommended the formation of a healthy competitive environment in schools and the application of motivational mechanisms.

Overall, studies have shown that motivation plays an important role in improving academic performance. Factors such as self-confidence, active learning strategies, and success-oriented goals are closely related to high academic results. Motivated students are able to apply the knowledge they have acquired to new situations and enjoy learning both during class and in extracurricular activities.

The application of modern information and communication technologies in the educational process also helps to increase motivation. The use of computer technologies creates a favorable emotional environment for students, provides an opportunity to learn information more deeply, and increases the effectiveness of general educational activities.

The role of emotions in the formation of motivation is of particular importance. In psychology, emotions are characterized as subjective reactions of a person to internal and external influences. Emotional states such as joy, fear, satisfaction or dissatisfaction affect human behavior and the decision-making process. Darwin explained emotions as an adaptive mechanism that serves to meet the needs of living beings. For this reason, emotions are considered an important component of the motivational structure.

Emotions affect a person's assessment of past and current situations, as well as planning future activities. Therefore, it is important to take into account emotional states for effective management of the motivational process. Interestingly, the effect of emotions does not always depend on their positive or negative nature. In some cases, negative emotions can motivate a person to work harder and achieve success, while positive emotions can enhance a sense of self-satisfaction.

It is important to create positive emotions in the learning process, especially at the initial stages. Such emotions increase students' self-confidence, create interest in learning and encourage them to take action. However, in certain cases, negative emotions can also be used as a motivational tool. For example, when a student's activity loses its meaning or interest decreases, a sense of competition and a desire for self-affirmation can lead to its reactivation. Thus, in order to form learning motivation in schoolchildren, their individual interests, emotional characteristics and the capabilities of modern teaching methods should be taken into account. An individual approach to each student creates conditions for revealing his abilities and strengthening his interest in educational activities.

Studies show that the motivating activity of teachers increases the attention, energy and learning results of students. For this purpose, it is recommended to make learning interesting and attractive, conduct individual conversations, involve parents in the educational process and reward successful students. At the same time, providing students with certain choice opportunities in the educational process and creating conditions for choosing topics that suit their interests provides significant support for the formation of motivation.

Conclusion

The conducted theoretical analysis shows that motivation is one of the main psychological factors determining the effectiveness of learning activities. The interest of pupils and students in the educational process, their academic achievements, learning activity and the quality of the results achieved are closely related to the level of motivation. Studies prove that highly motivated learners are more responsible, proactive and purposeful, and more successfully cope with the difficulties they encounter.

Studies also show that teacher-student relationships, family support, emotional environment, individual characteristics and modern teaching technologies

have a significant impact on the formation of learning motivation. Developing internal motivation, creating a positive emotional atmosphere, applying an individual approach and effectively using information and communication technologies are the main factors that increase students' interest in learning.

Thus, the formation of a motivating learning environment in educational institutions, taking into account the individual needs and interests of learners, as well as the application of modern pedagogical approaches can make a significant contribution to improving academic achievements and improving the quality of education. In this regard, the development of motivation should be considered one of the priority directions of the educational process.

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PHILOLOGICAL SCIENCES

ВИКОРИСТАННЯ ПРОЄКТНОЇ МЕТОДИКИ У ВИКЛАДАННІ ІНОЗЕМНОЇ МОВИ СТУДЕНТАМ ЗАКЛАДІВ ВИЩОЇ ОСВІТИ

Вакуленко Т.О.
Київський національний університет імені Тараса Шевченка
кандидат філологічних наук, доцент
Акмалдінова О.М.
Національний університет «Київський авіаційний інститут»
кандидат філологічних наук, професор

USE OF PROJECT METHODOLOGY IN TEACHING FOREIGN LANGUAGE TO STUDENTS OF HIGHER EDUCATION INSTITUTIONS

Vakulenko T.O.
Taras Shevchenko National University of Kyiv
PhD in Philology, Associate Professor
https://orcid.org/0009-0005-0703-083x
Akmaldinova O.
National University "Kyiv Aviation Institute"
PhD in Philology, Professor
https://orcid.org/0000-0001-7732-9179
DOI: 10.5281/zenodo.21364143

АНОТАЦІЯ

У статті досліджується використання методу проєктів на заняттях іноземної мови професійного спрямування у ЗВО. Здійснено детальну класифікацію проєктів та етапи роботи над ними. Стверджується, що проєктна технологія насамперед спрямована на розвиток самостійності студентів, а також стимулювання їх інтелектуального, пізнавального та творчого потенціалу. На думку автора, реалізація проєктної методики в процесі навчання іноземної мови дозволяє удосконалити навчальний процес, підвищити мотиваційний потенціал студентів і рівень володіння іноземною мовою.

ABSTRACT

The article examines the use of the project method in professional foreign language classes in higher education institutions. A detailed classification of projects and stages of work on them is carried out. It is argued that project technology is primarily aimed at developing students' independence, as well as stimulating their intellectual, cognitive and creative potential. According to the author, the implementation of the project methodology in the process of learning a foreign language allows to improve the educational process, increase the motivational potential of students and the level of proficiency in a foreign language.

Ключові слова: проєкт, проєктна методика, проєктний метод у викладанні іноземних мов, типологія проєктів, комунікативна компетентність, комунікативні уміння, професійні компетенції студентів.

Keywords: project, project methodology, project method in teaching foreign languages, typology of projects, communicative competence, communication skills, professional competencies of students.

Постановка та обгрунтування актуальності проблеми. Впровадження новітніх педагогічних технологій у навчальний процес є ключовою умовою для творчого, морального, інтелектуального розвитку особистості. Одним із дієвих способів навчання поряд із традиційними методами дедалі частіше застосовують нові підходи, серед яких – проєктний метод. Участь у проєктах і виконання проєктних завдань дають студентам можливість усвідомити практичну цінність вивчення іноземної мови. Регулярне застосування методу проєктів забезпечує глибше засвоєння навчального матеріалу, стимулює мотивацію до навчання а також пізнавальну активність.

Аналіз основних досліджень і публікацій. До проблем проєктної методики навчання іноземних мов зверталися зарубіжні та вітчизняні вчені. Визначенню видів проектів та їх основних характеристик присвячені дослідження Д. Дьюї, С.Естера, Г.Картера, В.Кілпатріка, Г.Томаса, Д.Фрід-Бута, С.Хейнса та ін. Даній темі присвятили свої наукові дослідження такі вітчизняні науковці: Е.Г.Арванітопуло, І.В. Волошанська, Л.М.Конопляник, С.В. Купрікова, В.М.Малик, З.Р. Ступчик, М.В. Супрун, О.М. Устименко, С.В.Щербина та ін.

Сьогодні цей метод є актуальним, він привертає увагу вчених та педагогів, як один із найефективніших інтерактивних форм навчання. Дослідник Саймон Хейнс в своїй книзі «Projects for the EFL classroom: resource material for teachers» надає готові до використання ідеї проектів, адаптовані до різних рівнів володіння мовою. Він пропонує практичні плани занять та структуровані рамки для інтеграції проектного навчання у викладання мови. Книга поєднує педагогічну теорію та практику, пропонуючи різноманітні завдання, орієнтовані на студента, які інтегрують чотири мовні навички (аудіювання, говоріння, читання та письмо). Книга

охоплює основні етапи управління проектами в класі: підготовку, планування, дослідження та презентацію [11].

Д.Фрід-Бут зазначає, що навчання мови відбувається у навчальній аудиторії і, зазвичай, існує розрив між мовою, якій студентів навчають та мовою, якої вони насправді потребують. Робота з проєктами може допомогти позбутися цього розриву [10].

Ступчик З.Р. у своїй роботі доводить, що метод проектів ефективно активізує творчу діяльність учнів на уроках англійської мови, сприяючи інтеграції мовної, когнітивної та соціальної компетенцій. Автор підкреслює важливість практичного застосування мови в реальних ситуаціях, що розвиває самостійність, ініціативу та командну роботу. Метод сприяє глибшому засвоєнню матеріалу через пошук інформації, обговорення та презентацію результатів. Автор виділяє ключові етапи роботи над проєктом, зокрема підготовчий, пошуковий, творчий, презентаційний та рефлексивний, спрямовані на підвищення мовленнєвої активності та подолання мовного бар'єру [6].

Щербина С.В. обґрунтовує ефективність проектного методу в навчанні іноземної мови у закладах вищої освіти, підкреслюючи його переваги: активізацію мовленнєвої діяльності, розвиток самостійності та критичного мислення. Автор виділяє ключові етапи реалізації проектів – від постановки завдання до презентації результатів. Метод сприяє інтеграції мовних навичок з контекстними знаннями, що підвищує мотивацію студентів. Рекомендується адаптувати проекти до рівня мовної компетенції та профілю спеціальності. Проєктна діяльність трансформує роль викладача у фасилітатора, підвищуючи мотивацію студентів та їхню конкурентоспроможність [9].

Аналіз літератури та специфіки використання методу проектів на заняттях з іноземної мови професійного спрямування показав, що застосування такого методу будується на основі особистісно орієнтованого та компетентнісного підходів, що забезпечують розвиток особистості майбутнього фахівця зі сформованою іншомовною комунікативною компетенцією [3,106].

Метою статті є проаналізувати педагогічну категорію проєктної діяльності, пояснити її особливості й етапи застосування на заняттях іноземної мови професійного спрямування, визначити її переваги як ефективної технології розвитку комунікативних умінь та професійних компетенцій студентів.

Виклад основного матеріалу дослідження. Сучасна педагогічна наука пропонує широкий спектр інноваційних методів і форм навчання, які мають на меті стимулювати інтелектуальний розвиток студентів, забезпечити глибоке засвоєння знань, сприяти набуттю компетентностей, необхідних для подальшої самоосвіти. Активізація цих процесів забезпечується завдяки проєктному методу. Основи методу були розроблені понад сто років тому завдяки діячеві американського прогресивного освітнього руху педагогом і філософом Джоном Дьюї[12].

У своїх працях Дж. Дьюї доводив, що дитина, яка є пасивним слухачем, безглуздо витрачає багато енергії. Тому він запропонував педагогам брати до уваги уяву та інтерес дитини. У сучасній методиці широко використовується ідея Дж. Дьюї, коли все навчання переломлюється через особистість студентів та їхні інтереси.

Учнем і послідовником ідей Джона Дьюї став американський професор Вільям Герд Кілпатрик, який дав назву способу навчання, запропонованому Дьюї: метод проєктів. Типологія проєктів Кілпатрика охоплювала різні галузі – від механіки, математики до вивчення іноземних мов.

На початку 1990-х років метод проєктної діяльності почав активно застосовуватися в українській освіті. Головною причиною такого відродження стало впровадження інформаційних технологій у навчальний процес. Основою методу проєктів є система розвитку пізнавальних навичок студента, його здатність практично застосовувати сучасні інформаційно комунікаційні технології, розвиток критичного мислення та розкриття творчого потенціалу, адже мета навчання іноземної мови полягає у розвитку комунікативної діяльності студентів, тобто у набутті практичного володіння мовою. Завдання викладача – активізувати діяльність кожного студента та створювати умови для їхньої творчої активності у процесі навчання [2].

Проєктна методика навчання іноземної мови – це сукупність методів, що допомагають студентам ефективно опановувати мовний матеріал шляхом виконання індивідуальних завдань. У процесі виконання проєктної роботи активно застосовуються такі лінгво-методичні принципи комунікативного підходу: практична спрямованість, що забезпечує використання мови у реальних або максимально наближених до реальних ситуаціях; застосування максимальної кількості каналів сприйняття інформації (візуальних, аудіальних, кінестетичних), що сприяє кращому засвоєнню матеріалу; мотивація студентів через вибір тем, які є цікавими і значущими для учасників, а також через активне залучення їх у процес навчання [5, 249].

У системі навчання іноземної мови широко використовується зорове автоматичне запам’ятовування лексичних і граматичних структур у ході розв’язання проблемних завдань, стимулюється розвиток творчого мислення та уяви. За допомогою проектної методики на занятті можна не тільки розширити словниковий запас студентів, але й закріпити вивчений лексико-граматичний матеріал. [4, 227].

Відповідно до ознаки домінуючого у проєкті методу можна виділити такі типи проєктів: дослідницькі, інформаційні, практико-орієнтовані, ігрові, творчі.

Дослідницькі проєкти мають бути з продуманою структурою, цілями, актуальністю дослідження, джерелами інформації, результатами.

Вони наближені до наукового дослідження. Дослідницькі проєкти передбачають вирішення наукової проблеми засобами іноземної мови.

Інформаційні проєкти спрямовані на збір інформації про якийсь об'єкт або явище, її аналіз та узагальнення фактів. Структура такого проєкта може бути позначена в такий спосіб: мета проєкту, предмет інформаційного пошуку, джерела інформації. Такі проєкти часто інтегруються з дослідницькими проєктами і стають їх органічною частиною.

Практико-орієнтовані проєкти спрямовані на вирішення практичного завдання, що пов'язане з майбутньою професійною діяльністю студентів. *Ігрові проєкти:* в яких студенти приймають на себе ролі, висловлені змістом проєкту та особливістю вирішуваної проблеми.

Творчі проєкти не мають опрацьованої структури і повинні оформлятися відповідно (створення відеофільму, рольової гри; написання есе, оповідання, газетної статті; малювання малюнку з описом).

Крім названих проєктів існуть *монопроєкти* і *міжпредметні проєкти. Монопроєкти* проводяться в рамках одного навчального предмета. *Міжпредметні* проєкти охоплюють декілька навчальних дисциплін. У такому проєкті можуть брати участь багато творчих груп, що мають дослідницькі завдання. Такі проєкти є особливо важливими під час вивчення іноземних мов на немовних факультетах.

Розрізняють проєкти з відкритою координацією і прихованою координацією. У проєктах з *відкритою координацією* бере участь безпосередньо координатор проєкта, спрямовуючи роботу окремих його учасників, організуючи окремі етапи проєкту, наприклад: якщо потрібно провести анкетування, взяти інтерв'ю, або домовитися про зустріч в офіційному закладі. У проєктах з *прихованою координацією* студенти працюють самостійно без участі координатора.

Щодо характеру контактів, то проєкти можуть бути міжнародними, регіональними чи внутрішніми. У *міжнародних проєктах* беруть участь представники різних країн. Вони представляють виключний інтерес, оскільки для їх реалізації потрібні засоби інформаційних технологій.

Внутрішні або *регіональні проєкти* організуються всередині одного навчального закладу, або між навчальними закладами усередині регіону однієї країни.

За кількістю учасників проєкти є *індивідуальні, парні,* або *групові.* За тривалістю виконання виокремлюють *короткострокові, середньострокові* та *довгострокові* проєкти.

Звичайно, на практиці найчастіше доводиться мати справу з змішаними типами проектів, в яких є ознаки використання дослідницьких та творчих. Кожен тип проєкту має той або інший вид координації, терміни виконання, етапи, кількість учасників. Тому при розробці проекту слід мати на увазі ознаки та характерні особливості кожного з них.

Проєктна діяльність у процесі вивчення іноземних мов здобувачами освіти ЗВО реалізується у три етапи: *підготовчий, основний та підсумковий*. *Підготовчий етап.* На цьому етапі відбувається вибір теми та типу проекту, формулювання цілей проєкту, кількості учасників, збір ідей для проєкту шляхом мозкового штурму; обговорення способів пошуку інформації та методів дослідження, планування роботи, формування груп та розподіл завдань між учасниками та встановлення термінів. На цьому етапі вдосконалюються граматичні та лексичні знання студентів та розвиток умінь вільно висловлювати свої думки в усній та письмовій формах. Перед організацією проектної діяльності викладачу необхідно вивчити індивідуальні здібності студентів групи та їхні інтереси.

Основний етап Даний етап передбачає самостійну роботу учасників проекту (збір інформації), проведення досліджень, аналіз та обговорення інформації всередині групи, інтеграцію нових знань, моніторинг діяльності студентів викладачем та оцінка проміжних результатів. Кінцевим результатом даного етапу може бути створення презентації, навчального відео, тематичної газети з однієї з фахових тем іноземною мовою, словника, буклетів.

Підсумковий етап охоплює захист готових проєктів перед аудиторією (презентації, доповіді, звіти, організація конференцій, пресконференцій, вікторин), аналіз групових і індивідульних досягнень, виявлення проблем та оцінювання проєкту. Оцінювання роботи кожного учасника групи відбувається за такими критеріями: виконання поставленого завдання, зміст проекту, повнота розкриття теми, оформлення проекту, обґрунтованість отриманих результатів, глибина знань і культура мовлення.

Щербина С.В. виділяє такі критерії оцінювання проєктних завдань: вибір студентами теми, практична спрямованість і значущість виконаної роботи; обґрунтованість запропонованих рішень, підходів і висновків; дотримання запланованих етапів проєктування, рівень самостійності та повнота виконання; ступінь творчого підходу, оригінальність матеріального оформлення та презентації проєкту; якість оформлення матеріалів; рівень доповіді – її повнота, аргументованість і переконливість; глибина знань за темою та ерудиція; а також повнота і обґрунтованість відповідей на запитання [9, 521].

Дослідник С.Хейнс неодноразово відзначав неможливість оцінити проектну роботу абсолютно об'єктивно [11,23]. У більшості випадків результати роботи студентів оцінюються по ступені їхньої участі в проекті і витрачених зусиллях. Для визначення результатів викладач може звернутися до записів, зроблених у ході роботи над проектом, і виділити плюси і мінуси роботи; скласти список питань для оцінки корисності проекту; обговорити проект із навчальною групою [9, 521].

Основні переваги методу проєктів: підвищення мотивації студентів до вивчення іноземної мови, вдосконалення мовних навичок, культури мовлення; розвиток умінь і навичок комунікативної

діяльності; перенесення фокусу з механічного запам'ятовування інформації студентами на реальне іншомовне спілкування; розвиток критичного мислення, дослідницьких та творчих здібностей; розвиток відповідальності студентів, самоорганізації, самостійності; розвиток у студентів умінь працювати у команді; висловлювати власні думки та захищати свою точку зору; використання мови для вирішення конкретних творчих та аналітичних завдань.

Роль студентів у проєктах: важливий перехід від пасивного слухача до активного учасника, який самостійно здобуває знання, аналізує інформацію та вирішує поставлені завдання. Викладач у проєктах виступає координатором, консультантом і фасилітатором процесу, а не лише джерелом готових знань.

Як і кожен вид діяльності, проєктна робота має не лише свої позитивні сторони, але й недоліки. До недоліків проектної діяльності можна віднести: проблему суб'єктивної оцінки творчої роботи; переоцінку своїх можливостей і потрапляння в стресову ситуацію через неможливість вкластися у визначені терміни; технічні накладки, які можуть вплинути як на процес роботи, так і на кінцевий результат [7, 260].

Висновок. Проєктна діяльність є однією з ефективних технологій підвищення мотивації до вивчення іноземної мови здобувачами освіти ЗВО, оскільки забезпечує впровадження інноваційного способу організації освітнього процесу за допомогою активної діяльності студентів. Проєктна методика мобілізує творчі здібності студентів, сприяє їх активності, розвиває винахідливість та навички мовленнєвої взаємодії. Цей метод поєднує на практиці принципи комунікативного, діяльнісного та особистісно орієнтованого підходів. Використання методу проєктів перетворює студента з об'єкта навчання у суб'єкт навчальної діяльності. Цей метод дає змогу студентам перейти від пасивного засвоєння готових знань до їх усвідомленого і активного набуття. Викладач виступає у ролі помічника і консультанта. У статті детально проаналізовано особливості проєктної технології, які обумовлюють підвищення мотивації до вивчення іноземної мови здобувачів освіти ЗВО.

Відповідно до ознаки домінуючого у проєкті методу виділяють такі типи проєктів: *дослідницькі, інформаційні, практико-орієнтовані, ігрові, творчі.* Крім названих проєктів існуть *монопроєкти* і *міжпредметні проєкти.* Розрізняють проєкти з *відкритою координацією і прихованою координацією.* Щодо характеру контактів, проєкти можуть бути *міжнародними, регіональними чи внутрішніми.* За кількістю учасників проєкти є *індивідуальні, парні,* або *групові.* За тривалістю виконання виокремлюють *короткострокові, середньострокові* та *довгострокові* проєкти. З'ясовано, що проєктна діяльність в процесі вивчення іноземної мови реалізується у три етапи: підготовчий, основний і підсумковий, кожен з яких передбачає використання певних вправ та стратегій. Метод проєктів доцільно застосовувати на заняттях іноземної мови зі студентами будь-якого рівня знань, віку і здібностей. Виконання проєктних завдань спонукають до вивчення іноземної мови та розвитку особистості студента.

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PHYSICS AND MATHEMATICS

ON ENERGIES OF GÜNALTILI GRAPHS

Günaltılı I.
Eskişehir Osmangazi University, Eskişehir,
Professor, Department of Mathematics and Computer Science, Eskişehir, Turkey
DOI: 10.5281/zenodo.21364150

ABSTRACT
In this paper, we presnt the definition of the energy of a graph and give precise way to calculate it terms of the spectrum and eigenvalues. We qlso state some basic properties. We will work mostly with simple undirected finite graphs.
Keywords: Graph, enery, spectrum, eigenvalue.

1. Introduction

To be precise a graph G is a pair G=(V(G), E(G)), where E(G)<V(G)XE(G). The set V(G) is called vertex set and E(G) is called edge set. The graph G is undirected if (u,v) edges in G implies (v,u) edges in G. If there are not edges of the form (u,u) G is called simple graph. If |V|=n and |E|=m, a finite graph G=(V,E) is said to be of order n and size m. If G is a graph of order n, we label vertices of the graph G as v_1 ,v_2 , …,v_n. The vertices v_i and v_j are adjacent in G, (v_i, v_j) is in E(G), The degree of a vertex v_i is a number of adjacent vertices to v_i and denoted by d_i =deg(v_i). The minimum degree of G is denoted by μ=μ(G), while the maximum degree of G is denoted by β=β(G). If β=μ=d, the graph G ıs called d-regular.

Walks on the graph will be important to understand the combinatorial proporties of the energy. A walk of length k in G is a sequence of the vertices $v_1,v_2,…,v_k$ such that (v_r,v_{r+1}) is in E(G) for r=1,2,…, k-1. We say that a walk is a closed walk if $v_1=v_k$. A path is walk where all vclosed walk with ertices are distinct. A cycle is a v vclosed walk with $v_i \neq v_j$ for $1 \leq i,j \leq n$. If there is a path between the vertices v_i ,v_j we said that the vertices are connected. The distance d(v_i,v_j) is the length of a shortest path between v_i and v_j. By using this distance , we define the diameter d(G) as the maximum distance between any pair of vertices, the eccentricity e(v_j) as the maximum distance between v_j and any other vertex, while the radius r(G) as the minimum eccentricity of vertices in the graph G.

Given the graphs G and H, we say that H is a subgraph of G if V(H)<V(G) and E(H)<E(G). A component C of G is a subgraph whewre every pair of vertices in V(C) A(A(G) of G is a square matrix of order n where(i,j)-entire if defined as are connected. The connected component that contains the vertex v_i is denoted by C(v_i). If a graph G is connected and has no cycles, G is called tree.

Definition 1.1. Let G be a graph and V_1,V_2 <V(G). If V=V_1< V_2, V_1 ∩V_2=0 and every edge in E(G) connects a vertex in V_1 with one in V_2 then G is called bipartite graph with (V_1,V_2) parts.

Definition 1.2. The adjacency matrix A=A(G) of G is a square matrix of order n where (i,j)-entry if defined as if v_i,v_j are adjacent, A_{ij} =1 and otherwise A_{ij}=0. The eigenvalues of A(G) are said the eigenvalues of the graph G. A graph on n vertices has eigenvalues counted with multiplicity, these will be denoted by $\lambda_1,\lambda_2,…,\lambda_n$ and labeled in a decreasing manner $\lambda_{1\geq}\lambda_{2\geq},…\geq\lambda_n$.

The set of alln eigenvalues of G is called the spectrum of G. Since A(G) isa self-adjoint then eigenvalues of G are necesarily real-values.

2. Main Results

Definition2.1. Let a graph G=(V,E) with vertex set be V=$\{v_1,v_2,…,v_n\}$ and adjacency A. Fort he matrix, we denoted its trace by Tr(A) and its absolute value$(AA^*)^{1/2}$ by |A|, then the energy of G is given by $\alpha(G)=Tr(|A(G)|)=\sum|A(G)|_{ii}$. The energy of the vertex v_i with respect to G, which is denoted by $\alpha(v_i)=Tr(|A|)=|A(G)|_{ii}$, for i=1,2,…,n, where$|A|=(AA^*)^{1/2}$ and A=A(G) is the adjacency matrix of G. The trace of A be decomposed as the sum of the positive linear functionals

π_i: M_n…..||<C, defined by $\pi_i(A)= A_{ii}$, $Tr(A)=\pi_1(A)+…+\pi_n(A)$. In this way the energy of a graph G is given by the sum of the individual energies of the vertices of G $\alpha(G)=\alpha_G(v_1)+…+\alpha_G(v_n)$. Positivity of the linear functional is very useful to give inequalities. For α_i being a positive linear functional on M_n impliea that the Hölder inequality is also valid. Let 0<r,p,q≤∞ be such that 1/r=1/p+1/q then Cauchy-Schwarz inequality,

$$\pi_i(|AB|^r)\leq \pi_i(AA^*)^{1/2}\,\pi_i\,(BB^*)^{1/2}.$$

Proposition 2.1. Let G=(V,E) be a graph with vertices $v_1,v_2,…,v_n$.Then

$$\alpha_G(v_i)=\sum u_{ij}^2|\lambda_j|,\ i=1,2,…,n.$$

Where λ_j denotes the j. Eigenvalue of the adjacency matrix of G and U=(u_{ij}) is the ortogogonal matrix whose columns are given by the eigenvectors of A.

Proof. Recall that the matrix A has n linearly indipendent real eigenvectörs which can in fact be chosen to be orthonormal. Let $u_1,u_2,…,u_n$ real ortonormal unit eigenvectors for A, with corresponding eigenvalues $\lambda_1,\lambda_2,....,\lambda_n$. If U=($u_{ij}$) the matrix whos πi e columns are $u_1,u_2,..,u_n$ denoted U=[$u_1,u_2,…,u_n$] and τ=∑($\mu_{ij}\lambda_i$) then U is ortogonal and $A=U\tau\tau U^{-1}$. ThusU implies that $AA^*=U(\tau\tau^*)^{1/2}\,U^t$ and then|

$$|A|=(AA^*)^{1/2}=U(\tau\tau^*)^{1/2}.....(^*$$

Since $[(\tau\tau^*)^{1/2}]_{ij}=\mu_{ij}|\lambda_i|$ and the vecrors u_i are ortogonal, according to (*), we have

$$|A|_{ii}=\sum u_{ik}[(\tau\tau^*)^{1/2}]_{kj}u_{ij}^t$$
$$=\sum u_{ij}|\lambda_i|u_{ij}=\sum u_{ii}^2|\lambda_j|$$

As desired.

Proposition 2.2. For a graph G and a vecror v_i

$$\alpha_G(v_i)\leq d_i^{1/2}$$

With equality if and only if the connected pomponent containing v_i is isomorfic to S_n v_i is its center.

Proof. We get the Cauchy-Schwarz inequality

$$\pi_i(AB) \leq \pi_i AA^*)^{1/2} \pi_i(BB^*)^{1/2}.$$

Since π_i is a positive, we may $\pi_i(|A|)^2 \leq \pi_i(|A|^2) = \pi_i(A^2)$.

Since $\pi_i(|A|) = \alpha_G(v_i)$ and $\pi_i(A^2) = d_i$, $\pi_i(|A|)^2 \leq d_i$, thus $\alpha_G(vi) \leq d_i^{1/2}$.

Proposition2.3.Let G be a connected graph with at least one edge. Then

$$(d_i/\beta)^{1/2} \leq \alpha_G(v_i) \text{ for all } v_i \text{ vertices}, \deg(v_i) = d_i.$$

Proof. Set $d_i = d$. The number of walks of size 4 can be bounded from above by

$$d^2 + d(\beta - 1) + (\beta - 1)(d - 1) = d^2\beta.$$

Indeed, there are d_i^2 walks that visit the vertex v_i twice, his are walks of the formv_i-v_j-v_i-v_k-v_i. Onthe other hand, there are at most $d_i(\beta - 1)$ walks of the formv_i-v_j-v_k-v_j-v_i with $k \neq i$. Finally the number of walks starting at v_i witch form quadriangle (v_i-v_j-v_k-v_l-v_i with iλ

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DETERMINATION OF ROLLING FRICTION IN BEARINGS OF LIFT AND LOWERING MECHANISMS (EXAMPLE ELABORATED FOR THE PROJECT OF CANAL ALONG THE DNISTER RIVER)

Starodub Yu.
Doctor of Physics and Mathematics, Professor,
Lviv State University of Life Safety (LSU LS)
Gushchak R.
Candidate of Technical Sciences, Senior Lecturer,
Lviv State University of Life Safety
Vorobets V.
Lviv State University of Life Safety
Cadet of LSU LS
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ABSTRACT

Method developed for the calculation of the friction coefficient in bearings, which are valid for various obstacles: spheres, cylinders, etc. Calculation of the friction coefficient work for the large obstacles according to the principle of scaling

The investigation is important for developing of practice for studying of bearings possibilities in practice of mechanisms usage in the field investigation for building objects along future project of water channel on the way from Baltic to Black sea.

Experiment conducted gives the possibility to calculate the bearing friction coefficient when they are used in mechanisms where express method is necessary and is impossible to obtain bearing out in machines which work in heavy planner conditions.

Method is useful in laboratory student's work when investigating bearings take place.

Keywords: rolling, friction in bearings, determination, mechanisms.

In this paper we present the results based on the previous investigations printed by the conference [1] concerning the necessity of investigation of situation with possible damage of the bearing in the wheels of the lifting mechanism on the river flow in the constructions to be rebuild along flow of Dniester River.

In the paper [1] the investigation was made for the mechanism presented on the Fig.1.

The paper is dedicated to manage the situation with necessity to investigate the friction influence on the wheels when the lift and sink mechanism is loaded with heavy weight [2] is used to work with structures on the river flow direction to make the possibility for boats flow in the direction on the rivers from the Baltic to Black sea.

We offer the option for experimentally determining the rolling friction coefficient of a bearing. Work is based on the results presented at the conference given in the reference [1]. The installation diagram is presented in Fig. 1. Here, shaft A is fixed to a bearing located in the object. A thread is wound around pulley B, the end of which is attached to a suspended load of mass m. There is a flywheel C on the shaft so that the descent is smooth and the thread does not break at the lowest point of descent. The radius of the pulley in the figure is R, the lowering height h_0 is taken as the boundary condition. Due to inertia, the flywheel will rotate in the same direction and the load will rise to the height *h*.

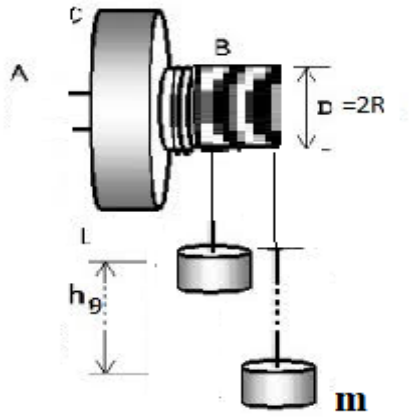

Fig.1 The rolling friction of bearings on a lift and sink mechanism. The disk L of greater diameter revolving on the axis A of the diameter 2R, R – radius, is hanging two objects, revolving connected with the rope with distance among them h_0 [1].

The formal presentation of the experiment is as follows:

Each bearing has its own rolling resistance moment *M*. It is equal to

$$M=\kappa N. \quad (1)$$

where κ – rolling friction coefficient of the bearing, which is necessary to be obtained experimentally, *N* – pressure force on the bearing, [2], [3]. The change in the potential energy of the load *m* is equal to the work of friction forces on the way down:

$$mgh_0 - mgh = Fm(h_0 + h), \quad (2)$$

where *h* – the height of the object with mass *m, g* – acceleration of gravity*;* see Fig.1.

From (2) we can see the force, which causes the friction

$$Fm = mg\,(h_0 - h)/(h_0 + h). \quad (3)$$

Multiplied by *R* gives the resistant moment *M*

$$M = R\,mg\,(h_0 - h)/(h_0 + h). \quad (4)$$

The pressure force on the bearing consists of the tension force of the thread, which is found from Newton's second law, and the weight of the rotating structure m. The statement follows from the theorem on parallel force transfer [3,4]. Thus

$$N = m(g - 2h_0/t2) + mkg, \quad (5)$$

Where t– the time of the accelerated move, mk is the integral mass of the bearing.

Putting the values *N* and *M* obtained from equals equations (4) and (5) into (1) we have

$$Rmg(h_0 - h)/(h_0 + h) = km(g - 2h_0/t2) + kmkg. \quad (6)$$

If mk, is known from (6) we can obtain *k*. If it is not possible to remove the rotating structure from the bearing and weigh it, then we can get rid of mk. To do this, we write (6) for two different loads $m1$ and m_k and subtract these equations. we will get

$$\kappa = Rg\frac{m_1\frac{h_0 - h_1}{h_0 + h_1} - m_k\frac{h_0 - h_2}{h_0 + h_2}}{g(m_1 - m_k) - 2h_0\left(\frac{m_1}{t_1^2} - \frac{m_2}{t_2^2}\right)} \quad (7)$$

Here h_1 and h_2 are the heights of lowering the loads $m1$ and m_2, respectively, t_1 and t_2 are the times of loads lowering.

An experiment also was conducted with the input data when in the formula for the *k* obtained from (1), (4), (5)

$$k = \frac{Rmg(h_0 - h)}{m(h_0 + h)\left(g - \frac{2h_0}{t^2}\right) + m_k g}. \quad (8)$$

Formula (8) is obtained from (7).

Experiment was conducted for the values h_0 =147.7 sm, R=10.5 mm. For the result of experiment: we put data into the Table. Also from (7) we have cofficients, also we numerate experiments in

Table

№	m, g	t, sec (sinking time)	h,sm(lifting height)
1	100	42.34	78.7
2	357. 83	21.28	99.7
3	386.46	20.43	101.7
4	444.84	19.1	103.7

According to the logarithmic method [8], the greatest accuracy in calculating *k* is obtained when the masses differ from each other as much as possible. According to the table, we find that this is a pair with numbers 1 and 4. Performing calculations for this pair according to (7), we obtain *k*(14)=1.45 mm, in accordance, *k*(12)=1.58 mm, *k*(24)= 1.1 mm. Average we get k=1.38.

Conclusions

We have obtained the method for the calculation of the friction coefficient for bearings, which is valid in approximation for various obstacles: spheres, cylinders, etc filled.

Calculation of the friction coefficient works also for the large obstacles according to the principle of scaling [4, 5, 6].

This work is important for developing of practice for studying of the bearing possibilities in practice of constructions use in the field research fieldwork of rebuilding and construction design of objects along future water channel on the way from Baltic to Black sea [7, 8, 9].

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POLITICAL SCIENCES

THE CONCEPT OF MILITARY SECURITY: IN THE NATIONAL SECURITY CONCEPT

Quliyeva A.
senior teacher
https://orcid.org/0009-0002-2633-7827
Imranov E.
colonel
Hamidov A.
Teacher
https://orcid.org/0009-0000-7154-3959
DOI: 10.5281/zenodo.21364164

ABSTRACT

The concept of national security is a broad concept that encompasses all aspects of a state's security. In this concept, military security occupies an important place and is one of the main factors for protecting the sovereignty of the state. Military security includes the preservation of the state's military power and increasing its defense capabilities against external threats. Military security is one of the main components of the national security concept of the state and includes the protection of the country's territorial integrity, sovereignty and national interests from military threats. This concept covers such main directions as increasing the defense potential of the armed forces, preventing external and internal threats, implementing modern defense strategies and cooperating with regional and global security systems. The article analyzes the essence of military security, the goals set and the ways to achieve them. At the same time, the increasing role of military security in modern international relations, the issues of ensuring interstate cooperation and the balance of power are emphasized. Military security is considered a concept of strategic importance in ensuring national security. The article extensively examines the main risks and challenges related to military security, including regional conflicts, terrorism, cybersecurity threats, and the use of modern technologies in the arms race. The national security concept emphasizes the importance of creating institutional and legal mechanisms to prevent these threats, effective management of military resources, and participation in international security systems. It emphasizes that the military component of the national security strategy should serve only the purpose of defense and that it should be implemented in accordance with the principles of international law. The main goal of the military security concept is to establish a sustainable and flexible defense system against both internal and external threats. This approach plays an important role in ensuring the sustainable development of the state, peace, and stability. The article shows that economic stability, the development of scientific and technical potential, and the involvement of society in national security issues are of particular importance in ensuring military security. Military security is not only the responsibility of the state, but also a complex approach to security that requires the joint participation of all segments of society in protecting national interests.

Keywords: national security, infrastructure security, computer security, political security, military doctrine.

Introduction

For Azerbaijan, which declared its independence for the second time in 1991, the formation of national security was of particular importance. Every state that is a member of the world community must form a national security policy in order to continue its existence. National security policy is a complex concept and varies depending on the region where the state exists, its border neighbors, and its ethnic composition. The formation of a market economy and civil society to ensure the national interests of the state is closely related to national security factors. There are certain national interests of the Republic of Azerbaijan, both in terms of national security and its future development prospects. The national interests of the Republic of Azerbaijan consist of a set of fundamental values and goals, as well as political, economic, social and other needs that ensure the progress of man, society and the state. The Republic of Azerbaijan, which is the organizer of such international logistics projects as Baku-Tbilisi-Kars, Baku-Tbilisi-Ceyhan, Baku-Tbilisi-Batun, which plays an active role in the transportation of goods between the countries of the North and South, as well as the East and the West, has always been in the center of attention of the world's countries due to its geographical location, significant energy resources, and the active role it plays in the transportation of goods between the countries of the North and South. Being a part of the international community, the Republic of Azerbaijan sees any attacks on its independence, sovereignty, territorial integrity, and constitutional structure as an attack on its national security and national interests. The chauvinistic nationalist state of the Republic of Armenia, which has been hostile to the territorial integrity of the Republic of Azerbaijan for many years, has displaced more than a million people from their ancestral homeland, and has shed the blood of hundreds of civilians, can be an example of these threats. In addition, extreme religious and political, ethnic extremism, and separatist activities are among the factors threatening the national security of the country. Terrorist acts that may cause panic within the country by being recruited by foreign forces, attempts or encouragement by certain groups to commit mass murder are among the main signs that may affect national security. It is known that in order to protect na-

tional security and ensure that society can live in prosperity, the active activity of the power structures is essential. It is essential that the power structures and the unified regular army forces stand guard over the homeland at all times and in all circumstances.

Currently, in Azerbaijan, the National Defense University of the Armed Forces of the Republic of Azerbaijan, the Police Academy, the Heydar Aliyev Academy of the State Security Service, the Academy of the State Border Service, the Academy of the Ministry of Emergency Situations, and the Higher Military School of Internal Troops are higher educational institutions of particular importance in the training of national personnel and conducting scientific research in the military field. The officer corps that graduated from the higher military educational institutions we have listed today is the main pillar of our army and security agencies. Our officers are ready at any moment to prevent any intervention that could harm the interests, international reputation, and national security of our republic.

1. The concept of National Security

National security (in American English, national defense) is the security and defense of a sovereign state, including its citizens, economy, and institutions, as perceived by the government as a duty. Originally conceived as protection from military attack, national security has been broadly understood to include non-military dimensions such as security from terrorism, crime reduction, economic security, energy security, environmental security, food security, and cybersecurity. Similarly, national security risks include, in addition to the actions of other states, the actions of violent non-state actors, drug cartels, organized crime, transnational corporations, and the consequences of natural disasters.

Governments rely on a range of measures to protect the security of the state, including political, economic, and military power, as well as diplomacy. They may also work to create a secure environment regionally and internationally by reducing the causes of transnational security, such as climate change, economic inequality, political isolation, and nuclear proliferation.

Potential causes of national security include the actions of other states (e.g., military or cyberattacks), violent non-state actors (e.g., terrorist attacks), organized criminal groups such as drug cartels, and the consequences of natural disasters (e.g., floods, earthquakes). Systemic factors of insecurity that may be transnational include climate change, economic inequality and marginalization, political isolation, and nuclear proliferation.

Given the wide range of risks, state security has several dimensions, including economic security, energy security, physical security, environmental security, food security, border security, and cybersecurity. These dimensions are closely related to elements of national power.

Governments are increasingly organizing their security policies in the form of national security strategies (NSSs). As of 2017, Spain, Sweden, the United Kingdom, and the United States are among the states that have done so. Some states also appoint a National Security Council or a National Security Advisor, an executive branch of government, who advises the president on matters of national security and strategic interest. The strategies of the National Security Council are reflected in national security plans for long-term, short-term, and contingency situations.

Although states differ in their approaches, various forms of coercive power, especially military capabilities, predominate. The scope of these capabilities has evolved. Traditionally, military capabilities were primarily on land or at sea, and in smaller states they still are. Elsewhere, potential war domains now include air, space, cyberspace, and psychological operations. Military capabilities designed for these domains can be used for national security purposes or, equally, for offensive purposes (the conquest and annexation of territory and resources).

Physical or Military Security

In practice, national security is primarily concerned with the management of physical threats and the military capabilities used to achieve this. That is, national security is often understood as the ability of a nation to mobilize military forces to secure its borders and to deter or successfully defend against threats (including physical ones such as terrorism), including military aggression and attacks by non-state actors. Most states, such as South Africa and Sweden, configure their military forces primarily for territorial defense; others, such as France, Russia, the United Kingdom, and the United States, invest in higher-cost expeditionary capabilities that allow their armed forces to sustain power and conduct military operations abroad.

Infrastructure or Critical Infrastructure

Infrastructure security is the security provided to protect infrastructure, particularly airports, highways, rail transport, hospitals, bridges, transportation hubs, network communications, media, electrical grids, dams, power plants, seaports, and critical infrastructure such as oil (oil refineries and water systems). Infrastructure security seeks to limit the vulnerability of these structures and systems to sabotage, terrorism, and pollution.

Many countries have established government agencies to directly manage the security of critical infrastructure (typically the Department of Homeland Security, private security agencies to protect facilities such as the US Federal Protection Service, and commercial transportation security units such as the Amtrak Police in the US). Critical infrastructure is vital to a country's core operations. Accidental or intentional damage can have a serious impact on the economy and essential services.

Some of the threats to infrastructure include:

- Terrorism: individuals or groups who deliberately target critical infrastructure for political gain (Mumbai Central Station and a hospital were deliberately targeted in the November 2008 Mumbai attacks).

- Sabotage: individuals or groups who promote environmental protection (Bangkok International Airport seized by protesters).

- Information warfare: countries that launch attacks to damage a country's cyber infrastructure, such

as hacking personal or banking information for personal gain, or for the purpose of gathering information. (Cyberattacks on Estonia and the 2008 South Ossetia War are examples).

- Natural disaster: a hurricane or other natural event that damages critical infrastructure such as oil pipelines, water and power grids (for examples, the economic impact of Hurricane Ike and Hurricane Katrina).

Virtual, Computer security or Cybersecurity.

Computer security, also known as Cybersecurity or Information security, refers to the security of computing devices such as computers and smartphones, as well as private and public networks and computer networks such as the Internet. It concerns the protection of hardware, software, data, people, and procedures that are part of the systems, and is increasingly important due to the increasing reliance on computer systems in most societies. Cyberspace is now considered a war zone, as unauthorized access to critical civilian and military infrastructure is now considered a major threat (one such example is the use of Stuxnet by the United States and Israel against the Iranian nuclear program).

Ecological

Ecological security refers to the integrity of ecosystems and the biosphere, especially their ability to support various life forms (including human life). As the impact of environmental damage by humans has increased, the security of ecosystems has attracted more attention. Ecosystem degradation, including topsoil erosion, deforestation, biodiversity loss, and climate change, affects economic security and can lead to mass migration, which in turn increases pressure on resources elsewhere. Ecological security is also important because most countries in the world are developing and dependent on agriculture, and agriculture is most affected by climate change. This impact has implications for the country's economy, which in turn has implications for national security. The scope and nature of environmental threats to national security, and strategies for addressing them, are a matter of debate. Climate change affects global agriculture and food security.

Romm (1993) classifies the main impacts of environmental change on national security as follows:

- Transnational environmental problems. These include global environmental problems such as climate change due to global warming, deforestation, and biodiversity loss.

- Local environmental or resource pressures. These include resource scarcity leading to local conflicts, such as disputes over water scarcity in the Middle East; The impact of agricultural failure in Mexico on migration to the United States and the erosion of fertile soil on the conflict in Syria. Environmental security in Rwanda, as population growth and the availability of arable land decrease, may also have contributed to the genocide there.

- The ecologically hazardous consequences of war. These include acts of war that disrupt or destroy ecosystems. Examples include the destruction of agriculture by the Romans in Carthage. Saddam Hussein's burning of oil wells during the Gulf War.

Energy and natural resources

Resources include water, energy sources, land, and minerals. Adequate natural resources are essential for a nation to develop its industry and economic power. For example, in the 1991 Gulf War, Iraq partially invaded Kuwait to gain access to oil wells, and one reason for the US counter-invasion was the value of those same wells to its economy.

The interrelationship between security, energy, natural resources and their sustainability is increasingly recognized in national security strategies, and resource security is now included in the UN Sustainable Development Goals. For example, in the United States, the military has installed solar photovoltaic microgrids on its bases in the event of a power outage.

2. The concept of military security

Military security refers to the ability of a nation-state to defend itself or to deter military aggression. Alternatively, military security refers to the ability of a nation-state to implement its policy choices through the use of military force.

The defense capability of a state is the military component of state security, provided by the armed forces and other state agencies at the level required to establish favorable relations with other states and prevent armed conflict.

The term "military security" is often considered synonymous with "safety" in a military context. One of the definitions of security given in the Dictionary of Military and Related Terms can be considered the definition of the concept of "military security". This is traditionally the earliest recognized form of national security. The scope of military security has expanded from traditional forms of conflict between nation-states to fourth-generation warfare between state and non-state actors. Military security is determined by the readiness and ability of the state to protect its interests and sovereignty, to resist military aggression and any other forms of external pressure, including military force [5] or blackmail from a position of power, as well as attempts to start a civil war, interethnic conflicts or terrorist activities using violence.

The following are important in the military security system:

- Intelligence, in particular military intelligence, the main task of which is to obtain and process information about the current or potential enemy, its military resources, combat capabilities and weaknesses, as well as to carry out a set of measures to obtain and process information about existing or probable information.

- theater of military operations;

- Counterintelligence, the task of preventing the intelligence activities of the relevant bodies of other states and anti-government, for example, extremist and terrorist organizations;

- Border troops, designed to protect the borders of the state, as well as maintain the appropriate regime in the border zone;

- Armed Forces. The most important external factors in ensuring the military security of the state are:

- Reduction (elimination) of military threats by political means,

- Development of a system of measures to reduce the number of potential adversaries and acquire new allies, prevent and localize military conflicts,

- Cooperation with neighboring states (including in the field of combating terrorism);

- Participation in defensive military-political alliances to collectively repel possible aggression;

- Participation in treaty processes for the reduction and limitation of weapons and armed forces; the creation of reduced arms level zones, demilitarization zones, nuclear security zones and open airspace on a mutual basis;

- Mutual limitation of all types of military activities.

Military Doctrine- defines the concept of "Military Security" as "the state of protection of the vital interests of the individual, society and the state from external and internal military threats associated with the use of military means." "The absence of a military threat or the threat of its application, characterized by the ability to resist it", Moreover, "military threat" is understood as a state of interstate or intrastate relations, characterized by a set of factors that, under certain circumstances, can lead to the emergence of a military threat. It is also characterized as interstate or intrastate relations characterized by the possibility of a military conflict between opposing parties. Military Doctrine of the Republic of Azerbaijan

Military doctrine is considered one of the important attributes of the state. Developed countries take various steps to develop their army building and military industrial potential, first of all, they strengthen the national legislative base. On the instructions of the President of Azerbaijan, Supreme Commander-in-Chief Ilham Aliyev, the national security concept of our country and the Military Doctrine based on this document were developed and adopted (approved by the Resolution of the Milli Majlis of the Republic of Azerbaijan No. 1029-IIIQR dated June 8, 2010).

What is the Military Doctrine, what is its role in strengthening the army building and defense potential? The Military Doctrine is considered one of the important attributes of the state. Sometimes it is also called the second or military constitution. After Azerbaijan gained independence, the preparation and adoption of the Military Doctrine was always on the agenda. Azerbaijan, first of all, was engaged in army building, acquired relevant practice, adopted laws implementing army building, and the Military Doctrine was developed. Our Military Doctrine combines both Azerbaijan's own national army building and international experience. Today, our Military Doctrine plays an appropriate basis for the protection of the territorial integrity of Azerbaijan and the continuous development of the army building.

The Military Doctrine considers it possible for Azerbaijan to participate in joint activities to establish peace and security in the international community. That is, it regulates Azerbaijan's activities in ensuring peace and security in the world. Azerbaijan already has considerable experience in participating in peacekeeping operations, and this experience is used to the maximum in building a national army. Azerbaijani servicemen, serving in hot spots around the world, also carry out propaganda for the Azerbaijani state.

The Military Doctrine encourages the creation of a military industrial complex in Azerbaijan and creates appropriate conditions for this. The Doctrine encourages the creation of a military industrial sector and considers it one of the state's priorities. That is, the Military Doctrine, as a constitutional provision, recommends the existence of a military industrial complex as one of the important directions of Azerbaijan's activity. Currently, the Ministry of Defense Industry in Azerbaijan produces more than 500 products. A large part of these products is purchased by the Azerbaijani Armed Forces. This means that the funds allocated for their purchase remain in the Azerbaijani market. The Azerbaijani military-industrial complex has already chosen a new model of development. Azerbaijan creates joint ventures with foreign military-industrial companies, jointly produces weapons and ammunition and military equipment, and at the same time, it can promote Azerbaijani products abroad by participating in international military exhibitions.

Conclusion. The concept of military security in the national security concept is of great importance for protecting the sovereignty and territorial integrity of the state. Military security, in addition to increasing the state's defense capabilities and military power, requires taking preventive measures against potential threats. One of the main factors for ensuring military security is the acquisition and development of modern weapons and technologies. At the same time, it is also important to increase the level of training and readiness of the military forces. International cooperation and strategic partnerships are important for strengthening military security. In order to further strengthen military security in the future, it will be important to develop the state's defense industry and introduce military innovations. This will help create a defense system that is durable and resistant to both internal and external threats. Military security is one of the main pillars of the national security concept, and its effective provision is a prerequisite for protecting the sovereignty, territorial integrity and national interests of the state. The concept of military security is not limited only to the formation of strong defense capabilities; this concept is also closely related to preventive measures, conflict prevention and expansion of international cooperation. The state's military security policy must be flexible, integrative and sustainable in accordance with the changing challenges of the modern era. In a globalizing world environment, unconventional threats, including hybrid wars, necessitate a review of cybersecurity strategies. In this regard, in addition to strengthening the country's defense potential, it is also important to actively involve citizens in the national security process. Military security can be ensured only through the coordinated application of national power elements (economic, political, diplomatic, etc.). This approach is of great importance for the internal stability of the state, strengthening its international position and contributing to regional security. As a result, the military security concept plays a strategic role in ensuring national security, creating the basis

for the long-term development of the country. As a result, it is concluded that military security is an integral part of the modern national security concept and its effectiveness depends on the coordinated activities of various elements of national power.

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TECHNICAL SCIENCES

INTEGRATING EDGE COMPUTING FOR ENHANCED RELIABILITY IN DISTRIBUTED VIDEO SURVEILLANCE SYSTEMS

Hudkov S.
Specialist/Master, Owner, GWF LLC,
8818 N Greenvale Court, Bayside, WI 53217, USA
https://orcid.org/0009-0003-7794-3306
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ABSTRACT

Distributed video surveillance systems have significant communication overhead, are dependent on cloud services, have latency in analytics and are prone to service outages due to network failures. In order to overcome the aforementioned challenges, this paper proposes an edge-computing based framework to improve the reliability, scalability and responsiveness of distributed surveillance environments. The proposed framework combines local processing of the video stream, real-time edge analytics, fault-tolerant operation, and adaptive load balancing between the edge nodes and the cloud infrastructure. The framework processes video streams locally at the data source, decreasing the communication overhead, the dependence on the cloud, and making it possible to monitor even in the event of a network outage. Moreover, the architecture enables efficient use of resources by dynamically distributing workloads and providing robust edge intelligence. Experimental assessments showed significant performance gains compared to traditional cloud-based surveillance solutions, such as a 42.8% decrease in analytics latency, a 48.6% decrease in network bandwidth usage and a 97.1% service availability. The framework persisted to have solid monitoring and effective resources utilization even in the face of bad network conditions. The proposed framework brings together the capability of fault-tolerant edge intelligence and distributed video analytics, ensuring a reliable and scalable framework for large-scale IoT-based surveillance systems with the need for continuous monitoring, efficient resource management, and resilient operation.

Keywords: Edge Computing, Distributed Video Surveillance, Video Analytics, Fault Tolerance, Internet of Things (IoT), Cloud–Edge Collaboration.

1. Introduction

As smart cities and smart infrastructures of every kind have proliferated, the need for distributed video surveillance technologies that can monitor locations on a 24/7 basis with high fidelity has skyrocketed. Typical cloud video surveillance solutions would require all video data to be transmitted to a data centre, resulting in latency issues, bandwidth limitations and potential single points of failure that affect the reliability of the system. With the growth of Internet of Things (IoT) devices, the amount of surveillance data increased and the drawbacks of relying on solely cloud-based solutions were clearly seen in the field [1, 2]. Edge computing has emerged as an effective paradigm that can bring computing intelligence closer to the data source, reduce the strain on the central cloud service and allow real time data analysis locally [3]. Complex video analytics functions such as detecting objects in video, object tracking and anomaly detection are performed at the network edge by edge nodes deployed in surveillance networks without the need for continuous cloud processing [4, 5]. The embedding of lightweight deep learning models at edge devices also allowed efficient human activity recognition and behaviour analysis in bandwidth-constrained environments [5]. The importance for surveillance applications in extremely critical applications like transportation hubs, critical infrastructure or healthcare facilities are also the capacity to keep on operating even when some nodes were not operational or the communications were interrupted [6, 7]. The previous studies are mainly on the hierarchical edge-cloud design that dynamically allocates the workload between the local nodes and the remote servers, and ensures efficient and persistent computation [8, 9]. Edge intelligence with distributed IoT architectures exhibited substantial improvements with respect to task execution latency and amount of data throughput in massive deployments [10]. Later on, studies also included the quantum fusion models and offloading schemes based on reinforcement learning to make further optimizations on resource allocation when changing the network condition [11] and [12]. While these developments have been made, no integrated framework exists that tackled local stream processing, fault recovery, latency reduction and elastic coordination of the cloud and edge in distributed surveillance applications. Unlike existing edge-based surveillance frameworks that primarily focus on local video analytics, the proposed architecture combines adaptive cloud–edge workload redistribution, fault-tolerant recovery through local persistence mode, and quantitative reliability modelling within a single integrated surveillance framework evaluated under long-term deployment conditions.

1.1. Motivation and Problem Statement

Continuing problems in video surveillance deployments included high latency of video analytics, bandwidth used to send raw video to cloud servers and service outages due to failures. The central cloud design introduced opportunities for vulnerabilities in the mission-critical monitoring scenarios where rapid response was a critical need. These limitations were a catalyst to the growth of a framework for edge computing that is able to accommodate local stream processing, continuous operation with fault tolerance, reduction of commu-

nication overheads, and dynamic load balancing between the distributed edge nodes and the cloud resources [5,7].

1.2. Research Objectives and Contributions

This study is mainly devoted to creating a framework that can be deployed in an edge computing system to improve the reliability and performance of distributed video surveillance systems. To attain this goal, the research concentrates on two main aspects.

The first is to increase system reliability, service continuity, with fault-tolerant monitoring, local persistence-based recovery and resilient cloud–edge coordination. These mechanisms also allow for seamless surveillance continuity when communication is lost and resources are unavailable.

The second objective is to improve performance and resource efficiency through localized video analytics and adaptive cloud–edge workload redistribution. By processing video streams at edge nodes and dynamically balancing computational workloads, the framework reduces communication overhead, minimizes analytics latency, and enhances processing throughput.

The proposed framework contributes to these objectives through three integrated components: (i) local stream processing for real-time edge analytics, (ii) adaptive cloud–edge load balancing for efficient workload redistribution, and (iii) fault-tolerant recovery based on local persistence mode and redundant edge coordination. The effectiveness of the framework is evaluated using latency, bandwidth utilization, throughput, fault recovery, service availability, and event detection performance metrics.

2. Related Work

With the introduction of edge computing, deep learning and IoT architectures, distributed video surveillance systems (DVSS) have significantly developed and received significant attention in the area of detection, analytics, reliability and privacy. Rojas et al. [13] used a CNN on the network edge to recognize harmful objects in the surveillance stream, and showed that models based on deep inference can be highly accurate and still be feasible to compute at the edge of the network. Myagmar-Ochir and Kim [14] provide a detailed survey of the use of video surveillance in smart city systems and conclude that edge-cloud hybrid system is the most prevalent one for scalable urban surveillance. To tackle the above problems, Shao et al. [15] suggested an intelligent surveillance platform which combined deep tampered detection with secure edge-cloud services, both of which considered performances of analytics and data integrity in distributed deployments. Elçi and Ünlü [16] created a real-time autoencoder-based anomaly detection model for warehouse monitoring to prove the viability of light weight unsupervised models at the edge for real-time equipment-human interaction monitoring. To monitor and detect abnormalities in crowds, Suresh et al. [17] proposed IntVAO tracker which can track multiple targets even when targets are occluded in live surveillance images. Cho et al. [18] tackled the privacy issue of surveillance system by developing an encryption method for region of interests (ROI) that can be selectively decrypted, thus providing data protection without the need to interfere with the analytics pipeline. Evany Anne and Sivakumaran [19] presented their intelligent crime surveillance system with deep classification models which is valid at the operational latency constrained conditions for real time systems. Dautov et al. [20] showed how to build the reliability of surveillance at the metropolitan scale, by combining IoT and edge computing paradigms, and adopting distributed monitoring pipelines, which are robust to partial communication failures. Chandrasekaran et al. [21] studied the advent of edge computing revolution for intelligent systems and presented architectural shift from centralized cloud computing towards distributed edge computing for inference. Aminiyeganeh et al. [22] conducted a performance comparison between different stream processing efficiencies of the video analytics frameworks in a heterogeneous sensor network for smart city surveillance. In the context of distributed analytics, Dutta et al. [23] further developed an edge integrated IoT system design with the help of aerial platform coordination, which was applied to the mobile surveillance scenario. Kamruzzaman [24] investigated the security management for 6G-based edge-cloud system, where the concept of redundancy-based availability strategies for next generation surveillance system was investigated. Liu et al. [25] designed a reinforcement learning based task offloading scheme for traffic video surveillance, which aims to optimise the allocation of the computational resources under the dynamic network condition. Gibelli et al. [26] used next generation surveillance systems for forensic identification: 3D superimposition with high precision was achieved for subject recognition using the video feed. Liu et al. [27] designed a vehicle surveillance system based on image fusion and parallel computing which can be applied to enhance the detection throughput for the multi-lane monitoring system. Ismail et al. [28] applied IoVX ideas to the homeland security surveillance in smart cities, designing a layered architecture that involves cameras, edge processors and cloud analysis servers. To retrieve a person in surveillance video, Tseng et al. [29] used instance segmentation based on deep learning to get a high accuracy in the crowded scene conditions. To support privacy protection in surveillance streams, while preserving the event detection performance, the idea of adaptive transformation techniques was proposed by Saini et al. [30] which can be configured as per the user requirements. To validate the smart video surveillance system, which is entirely built on edge computing, Cob-Parro et al. [31] demonstrated that it is possible to process multiple streams of video in real-time without a continuous connection to the cloud, thus setting the benchmark for edge-first approaches in video surveillance.

2.1. Research Gap and Study Motivation

Although some significant work was done in individual components such as edge analytics, fault-tolerant continuous operation and real-time analytics, existing literature does not integrate all these capabilities within a unified framework with adaptive cloud–edge coordination in distributed video surveillance systems. Previous studies focused on one or a few of these dimensions in specific and limited deployments. Moreover, quantitative assessment models that measure the

capabilities of edge-enabled architectures against cloud-based baselines in multiple aspects of reliability and performance have been limited in quantity [35,36]. To fill these gaps, this study proposed an integrated edge computing framework for distributed surveillance, and extensively experimented the proposed framework in terms of latency, bandwidth, throughput, fault tolerance, availability and detection accuracy metrics.

Previous studies have demonstrated the effectiveness of edge computing for video surveillance applications. For example, Cob-Parro et al. [31] proposed an edge-based surveillance architecture for local video processing without continuous cloud connectivity. However, their framework primarily focused on edge-centric analytics and did not address adaptive cloud–edge workload redistribution, fault-recovery mechanisms, or quantitative reliability evaluation. In contrast, the proposed framework integrates local stream processing, adaptive cloud–edge load balancing, fault recovery through local persistence mode and redundant edge coordination, and quantitative reliability modelling within a unified architecture. Furthermore, unlike existing streaming-oriented approaches, the proposed framework is evaluated through a 30-day deployment using fault-injection scenarios and multi-metric assessment, including latency, bandwidth utilization, throughput, fault tolerance, service availability, and event detection accuracy. Table 1 further highlights the limitations of existing approaches and the distinguishing capabilities of the proposed framework.

Table 1

Summary of Related Work on Edge Computing-Based Video Surveillance Systems

Reference	Approach	Key Feature	Limitation	Finding
[32]	IoT–Edge Integration	Smart stadium fault monitoring	Domain-specific	Reduced node failure recovery time
[33]	Federated Learning	Privacy-preserving surveillance	Communication overhead	Improved resilience via federation
[34]	Deep-Framework	Scalable real-time video analysis	Scalability constraints	Low-latency stream processing achieved
[35]	Edge Intelligence	Resource-efficient analytics	No fault model	Latency reduced via edge offloading
[36]	AI-Driven Edge	Smart healthcare IoT monitoring	Healthcare-focused	High availability in distributed IoMT
[37]	Streaming Video IoT	Video analytics on IoT nodes	Benchmark limitations	Efficient stream analytics at the edge
[38]	Edge HPC for AI	Neural network inference hardware	Hardware-specific	Faster AI inference on edge hardware
[39]	Traffic Monitoring	Real-time traffic analytics	Traffic-domain only	Sub-second edge video processing
[40]	Person Detection	Combined detection + edge compute	Single-use-case	Accurate detection at edge nodes

3. Proposed Edge-Enabled Surveillance Framework

In order to address the intrinsic drawbacks of cloud-based video surveillance systems, the proposed edge-based video surveillance system is based on a multi-tier distributed architecture, comprising of features such as local video stream processing, real-time video analytics at the edge, fault tolerance, and adaptive cloud–edge load balancing. The framework is based on three hierarchical levels: camera-level capture nodes, edge processing nodes and cloud coordination servers. The raw video streams are continuously captured by the camera nodes, and are transmitted only to the local edge nodes. Edge nodes process incoming streams, decoding them in real-time, pre-processing them, and then performing deep learning inference to find actionable metadata including motion events, object classifications, and anomaly flags without uploading full video content to the cloud. Summarized analytics outputs are sent to the cloud tier which acted as a coordination layer for updates to the policies, synchronization of models and overflow processing in high demand situations. The edge node includes a local analytics pipeline, which comprised a video decoder, a pre-processing module, a lightweight inference engine and a fault monitor. The experimental validations are also able to validate this integrated architecture, proving that this approach significantly reduced latency, bandwidth consumption, increased throughput, and ensured high availability of the service, maintaining an availability of 97.1% and a detection accuracy of 94.3% throughout the entire evaluation period.

3.1. System Architecture

The system architecture consists of three hierarchical tiers, each performing a specific function. The perception tier comprises IP cameras and capture devices with embedded IoT connectivity that deliver video streams to co-located edge nodes. The edge processing tier consists of distributed edge servers equipped with GPU-accelerated video analytics capabilities and local storage. These servers execute video analytics pipelines that include video frame decoding, object detection, event classification, and anomaly detection. To ensure processing continuity and analytics availability, each edge node incorporates a redundant processing queue and a local event log, enabling uninterrupted operation during cloud communication failures. The coordination tier operates on cloud resources and manages distributed model updates, global policy

enforcement, and overflow processing for computationally intensive analytical tasks that cannot be handled by local edge nodes.

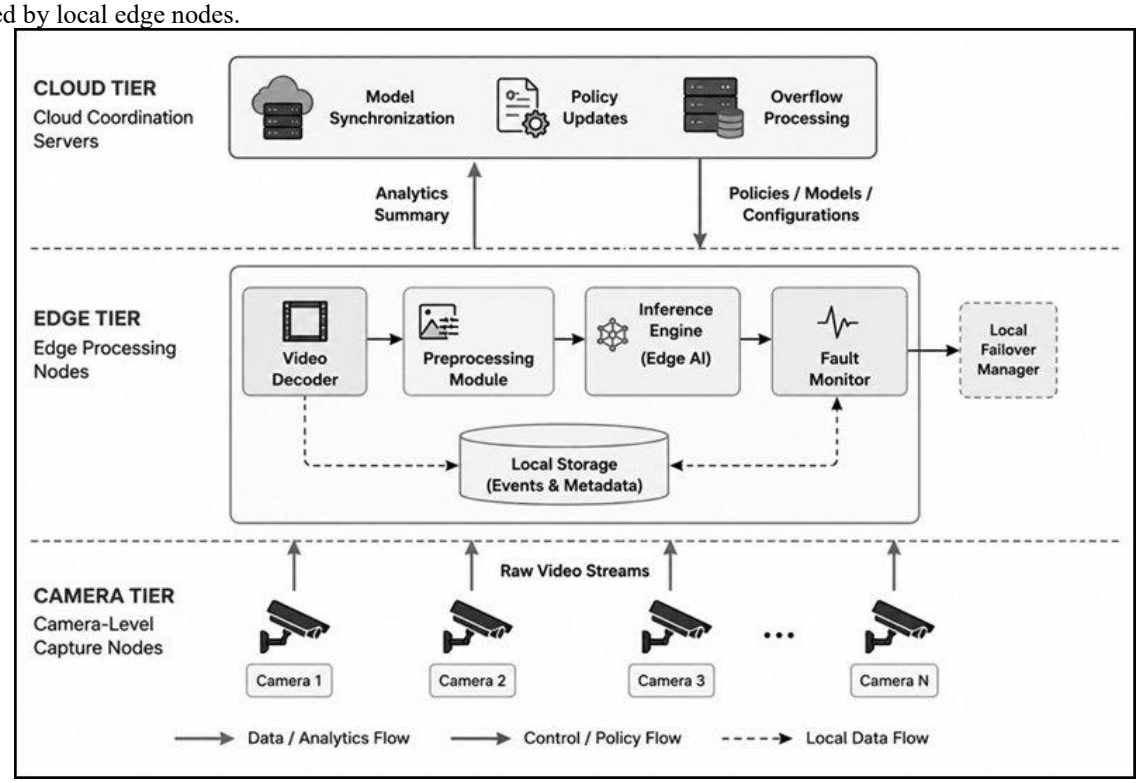

Figure 1: Proposed Edge-Enabled Surveillance Framework Architecture

Inter-tier communication is handled by a simple message exchange protocol that reduced the overhead of the message exchange while still providing support for time-stamped event delivery. We envision a camera-level capture node, edge node for processing, and a cloud coordination server as part of the proposed surveillance framework as shown in Figure 1. The model synchronization, policy updates, and overflow processing are handled on the cloud, whereas the video stream is processed locally in the decoding, pre-processing, inference and fault monitoring modules, enabling reliable, low latency and fault tolerant video surveillance operations.

As illustrated in Figure 1, the camera-level capture nodes continuously acquire raw video streams and transmit them to the associated edge processing nodes. Within each edge node, the Video Decoder converts incoming compressed streams into analyzable video frames, while the Preprocessing Module performs frame normalization, resizing, and quality enhancement operations. The Inference Engine (Edge AI) executes the deployed YOLOv8-S model to perform object detection, event classification, and anomaly identification in real time. The Fault Monitor continuously supervises node health, communication status, and processing performance, triggering recovery procedures when failures or communication disruptions are detected. The Local Storage component maintains temporary event logs and analytics metadata, enabling uninterrupted operation during cloud outages, whereas the Local Failover Manager coordinates local persistence and recovery actions. At the cloud coordination tier, the Model Synchronization module distributes updated AI models to edge nodes, the Policy Updates module enforces global surveillance policies and configuration settings, and the Overflow Processing module executes computationally intensive tasks that exceed local edge capacity. The data flow shown in Figure 1 consists of raw video streams moving from the camera tier to the edge tier, analytics summaries being transmitted from edge nodes to the cloud tier, and policy or model updates being propagated from the cloud tier back to edge nodes.

3.2. Edge Analytics and Stream Processing

The edge analytics pipeline performs a sequence of operations on incoming video frames, beginning with frame acquisition and pre-processing, followed by feature extraction and inference. The following mathematical formulations are used to model and optimize processing throughput and resource utilization at each edge node:

$$T_{\mathrm{e}} = T^{\mathrm{d}} + T_{\mathrm{p}} + T_{\mathrm{i}} + T_{\mathrm{t}} \quad ...(1)$$

Total edge processing latency T_{e} was modeled in equation (1) as the sum of decoding (T^{d}), pre-processing (T_{p}), inference (T_{i}), and transmission (T_{t}) latencies of each of the nodes.

$$BS(\%) = \frac{B_{raw} - B_{edge}}{B_{raw}} \times 100 \quad ...(2)$$

The bandwidth savings (BS) is quantified as %age reduction from the raw stream bandwidth (B_{raw}) to the reduced bandwidth (B_{edge}) of edge-processed metadata bandwidth as per Equation (2).

$$\eta = \frac{\Sigma_{\mathrm{i}} F_{\mathrm{i}}}{N \times T_{window}} \quad ...(3)$$

To compute processing throughput (η), Equation (3) calculated the total number of frames processed (ΣF_i)over the number of edge nodes (N) times the evaluation time window (T_{window}).

$$W(f) = \alpha C(f) + \beta M(f) + \gamma L(f) \quad ...(4)$$

The frame priority weight W(f) is defined as a combination of content complexity $C(f)$, motion magnitude M(f) and L(f) queue length with the priority of contents, motion and queue length controlled by the coefficients α, β and γ respectively as shown in equation (4).

$$P_{sat} = 1 - e^{\left(-\frac{\lambda}{T}\right)} \quad ...(5)$$

In Equation (5), P_{sat} = probability of resource saturation at the edge node of arrival rate of processing requests at the edge node λ, and available processing capacity, T.

3.3. Cloud–Edge Coordination and Fault Recovery

The cloud--edge coordination module controlled the dynamic workload distribution and introduced automated fault recovery mechanisms that reacted to communication outages and failures of the edge nodes. If a surveillance edge node experiences a cloud communication failure as determined by repeated heartbeat timeouts, it entered a fall-back path, where everything else worked in a local persistence mode – events are recorded locally and all analytics are performed at the edge until the cloud is restored. The following mathematical formulations are used for the fault recovery and coordination behaviours:

$$P_{fail(t)} = 1 - e^{-\mu t} \quad ...(6)$$

In Equation (6), the cumulative failure probability $\left(P_{fail(t)}\right)$ at any edge node is modelled as an exponential function of failure rate (μ) and elapsed operation time (t).

$$T_{recovery} = T_{detect} + T_{failover} + T_{sync} \quad ...(7)$$

According to equation (7), the total recovery time of $T_{recovery}$ can be divided into the following three parts: failure detection time T_{detect}, failover switching time $T_{failover}$, and post-recovery synchronization time T_{sync}.

$$U_{node(k)} = \frac{CPU_K \times W_1 + MEM_K \times W_2 + Q_k \times W_3}{W_1 + W_2 + W_3} \quad ...(8)$$

The composite utilization $U_{node(k)}$ of node k is calculated using Equation (8) as a weighted average of the CPU load, memory occupancy and queue length with normalization weights w_1, w_2 *and* w_3.

$$\Delta task = \underset{k}{argmin} \; [U_{node}(k)] \quad ...(9)$$

Subject to

$$subject\ to\ Q_k < Q_{max}$$

The reassignment target node (Δtask) is selected as minimum composite utilization node as per equation (9) considering queue capacity constraint Q_{max}.

$$A = \frac{T_{total} - T_{downtime}}{T_{total}} \times 100 \quad ...(10)$$

In Eq. (10) the service availability A is defined as the %age of uptime $(T_{total} - T_{downtime})$ over the total evaluation time T_{total}.

4. Experimental Methodology

The experimental methodology set up a controlled testbed environment, determined quantitative performance metrics, and determined how to evaluate and validate the proposed edge-enabled framework against the baseline architectures on multiple dimensions. The experimental testbed consisted of eight edge nodes (NVIDIA Jetson Xavier NX with 8 GB RAM and 384-core GPU) that are interconnected through a 1 Gbps switched Ethernet fabric, and a cloud server (32-core Intel Xeon, 128 GB RAM, 4× NVIDIA V100 GPU) provided the coordination tier. A total of eight 1080p IP cameras created synced video streams, resulting in about 180GB of raw video per hour, across all of the nodes. The evaluation data set was created by merging 120 hours of the publicly available surveillance footage from the VIRAT Video Dataset with 60 hours of synthetic multi-camera streams created by the testbed that contained pedestrian and vehicle movements and 2,400 manually-labeled anomaly events. The evaluation period of 30 days had network failure scenarios such as link failure, packet loss (5-30%) and node crash injected at controlled time intervals using the Linux Traffic Control (tc) utility.

4.1 Event Detection Model Configuration

For event detection and video analytics, the framework employed the YOLOv8-S object detection network due to its favorable balance between detection accuracy and computational efficiency for edge deployment. The model was trained to recognize four surveillance event categories, namely pedestrian activity, vehicle movement, crowd gathering, and anomalous events. Input video frames were resized to a resolution of 640 × 640 pixels prior to inference. Model training was performed using the PyTorch framework, while inference on edge devices was accelerated using NVIDIA TensorRT.

The Fault Monitor continually monitors the health of nodes, communication status and processing performance and initiates recovery in the event of failure or communications outages. The Local Storage component keeps temporary event logs and analytics metadata onsite, so that operations can continue in the event of a cloud outage, while the Local Failover Manager initiates local persistence and recovery actions. On the cloud coordination tier, the Model Synchronization module pushes the updated AI models to the edge nodes, the Policy Updates module applies global surveillance policies and settings to the nodes, and the Overflow Processing module runs intensive processing tasks that cannot be performed on the edge nodes.

4.2 Dataset Partitioning and Training Protocol

A total of 126 hours (70%) of the combined data (VIRAT surveillance footage + synthetic multi-camera video streams) was used for training, 18 hours (10%) for validation, and 36 hours (20%) for testing. The 2400 manually annotated anomaly events were divided into the three partitions, maintaining class distributions and the diversity of the events, with ~ 1680 training events, ~ 240 validation events, and ~ 480 testing events. To guarantee a reproducible partition of the data sets and a training of the models, the same random seed was used in all experiments (42). No video sequence or camera stream was used in more than one partition, thus no data leakage was occurring between the training, validation and testing sets. To make sure that there is no commonality between the training and evaluation data sets, the

partitioning was done at the video-sequence level, instead of at the frame level.

Event detection model was trained with an initial learning rate of 0.001, a cosine annealing learning-rate schedule and the AdamW optimizer. Training was done for up to 100 epochs and batch size was set to 32. In order to avoid overfitting, an early stopping was used with patience of 15 epochs, according to the validation loss. Model selection was performed using the best validation performance, and all reported detection results were obtained exclusively from the independent test set. Detection accuracy was computed on the independent test set as the ratio of correctly classified event instances to the total number of annotated event instances across all four surveillance categories.

Each experimental scenario was executed ten independent times under identical conditions. Results are reported as mean ± standard deviation. Statistical significance was assessed using a paired t-test with a significance level of $\alpha = 0.05$.

For brevity, Tables 2–6 report the mean values obtained across ten independent runs, while standard deviations remained below 5% of the corresponding mean values for all reported metrics.

5. Results and Discussion

Results from the experiments showed the proposed edge-enabled framework significantly achieved a higher score than the cloud-centric and edge-only baselines in all six-evaluation metrics. The integrated architecture demonstrated consistent improvements in latency reduction, bandwidth savings, throughput gains, fault tolerance, service availability, and detection accuracy compared with baseline architectures.

5.1. Latency, Bandwidth, and Throughput Analysis

A comparison of the latency of the analytics across the five evaluation scenarios for the cloud-centric baseline, edge-only system and the proposed system is presented in Table 2. The proposed architecture achieved the lowest latency across all evaluation scenarios in each of the five scenarios, with the average processing delay in cloud-centric setup being 128.4ms and in the proposed setup it is 73.5ms, which is 42.8% less. Edge-only system had intermediate latency reductions (82.3 ms on average) but it was not as load balancing and fault tolerant as the proposed system. The steady decrease in latency under high load conditions (Scenario 4 and 5) confirmed the ability of adaptive task distribution to avoid an accumulation of tasks in each node.

Table 2

Analytics Latency Comparison across Evaluation Scenarios (ms)

Scenario	**Cloud-Centric (ms)**	**Edge-Only (ms)**	**Proposed (ms)**	**Reduction vs Cloud (%)**	**Reduction vs Edge (%)**
Scenario 1 (Low Load)	112.3	75.4	65.2	41.9%	13.5%
Scenario 2 (Medium Load)	124.8	80.1	71.3	42.9%	11.0%
Scenario 3 (High Load)	131.6	84.6	74.8	43.2%	11.6%
Scenario 4 (Network Stress)	138.9	87.1	78.4	43.5%	10.0%
Scenario 5 (Failure Injection)	134.4	84.3	77.8	42.1%	7.7%
Average	128.4	82.3	73.5	42.8%	10.7%

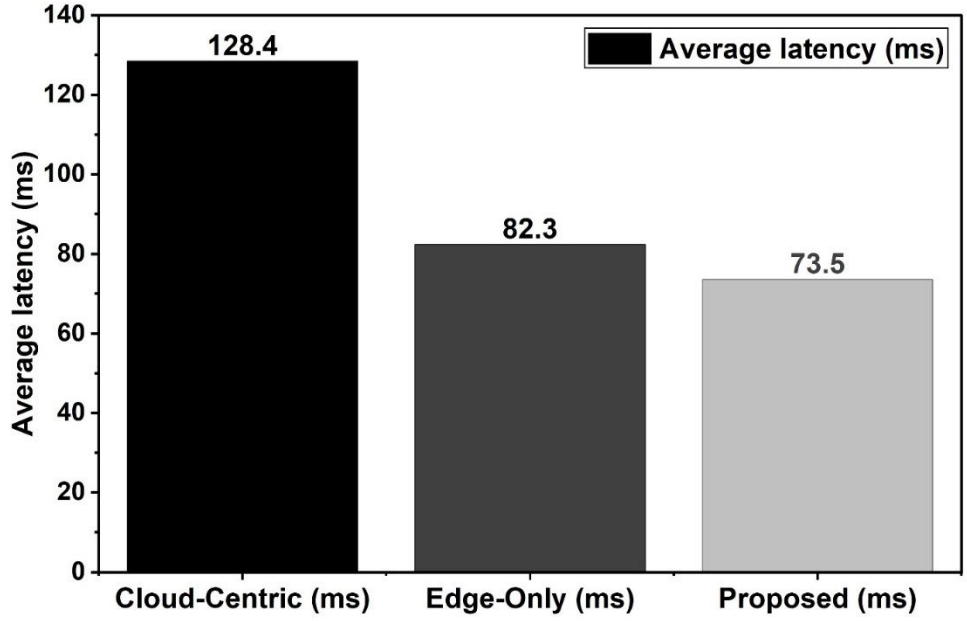

Figure 2 (a): Average analytics latency (ms) comparison across cloud-centric, edge-only, and proposed framework architectures.

As shown in figure 2 (a), it is confirmed that the proposed framework has the lowest average latency of 73.5ms which is 42.8% lower when compared to cloud based baseline, thus proving the effectiveness of local edge processing. The results shown in the figure 2 (b) indicate that in any case, the proposed framework attained the lowest end-to-end latency followed by edge-only architecture. The cloud-based system was found to have much greater delays. Results verified the efficient cloud edge coordination to enable higher responsiveness, faster processing and better real-time performance.

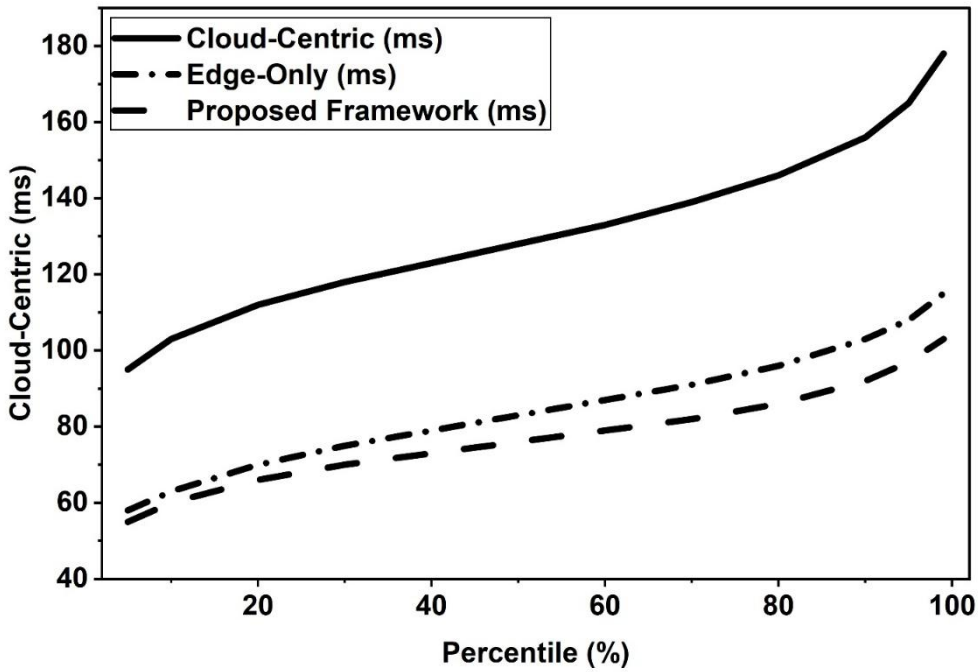

Figure 2(b): Cumulative Distribution of End-to-End Latency for Cloud-Centric, Edge-Only, and Proposed Surveillance Frameworks

The results of the bandwidth utilization measurements for both the proposed framework and cloud-centric baseline are shown in Table 3 in five edge nodes. The suggested scheme decreased the bandwidth utilisation from 92.1% to 47.3%, representing a 48.6% reduction. This decrease was due to edge processing of video streams, whereby only structured analytics metadata

were transmitted to the cloud tier instead of raw video. For absolute bandwidth savings, Node 3 showed the largest reduction (46.2%). Peak Saving (%) represents the maximum instantaneous bandwidth reduction observed during the 30-day evaluation period relative to the cloud-centric baseline. Node 3 also achieved the highest peak saving of 52.1%, reflecting periods of intensive video traffic where edge processing produced the greatest communication reduction.

Table 3

Bandwidth Utilization by Edge Node (%)

Edge Node	Cloud-Centric (%)	Proposed (%)	Reduction (pp)	Reduction (%)	Peak Saving (%)
Node 1	92.3	47.5	44.8	48.5%	51.2%
Node 2	88.7	45.6	43.1	48.6%	50.4%
Node 3	95.1	48.9	46.2	48.6%	52.1%
Node 4	90.4	46.2	44.2	48.9%	50.8%
Node 5	93.8	48.1	45.7	48.7%	51.5%
Average	92.1	47.3	44.8	48.6%	51.2%

The result in figure 3 indicates that the proposed framework was able to achieve bandwidth utilization less than 49% for all five edge nodes as compared to the cloud-centric baseline that achieved bandwidth utilization of more than 88%, which further validates consistent network load reduction.

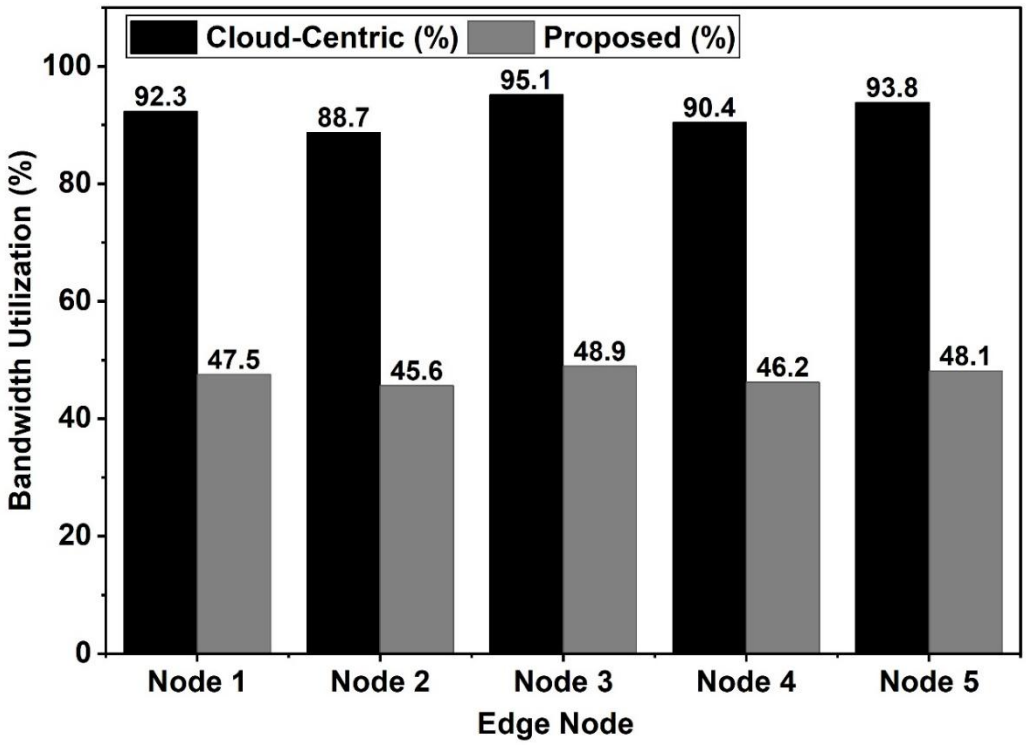

Figure 3: Bandwidth utilization (%) comparison per edge node between cloud-centric and proposed framework architectures.

Table 4 shows the comparison of the processing throughput for both architectures for a 30-minute observation time. The proposed framework achieved an average throughput of 38.4 frames per second while the cloud-centric baseline was 29.4 fps, which is a 26.3% increase. The adaptive load balancer redistributed tasks away from the transiently overloaded nodes and thus led to throughput gains beyond 10 minutes.

Table 4

Processing Throughput Over 30-Minute Evaluation Window (frames/sec)

Time (min)	Cloud-Centric (fps)	Proposed (fps)	Throughput Gain (fps)	Gain (%)	Node Load Balance (%)
0–5	28.2	28.2	0.0	0.0%	62.4%
5–10	29.1	33.5	4.4	15.1%	71.3%
10–15	30.4	35.8	5.4	17.8%	78.9%
15–20	29.8	37.1	7.3	24.5%	83.2%
20–25	28.6	38.0	9.4	32.9%	87.6%
25–30	29.3	38.4	9.1	31.1%	89.4%
Average	29.4	38.4	9.0	26.3%	78.8%

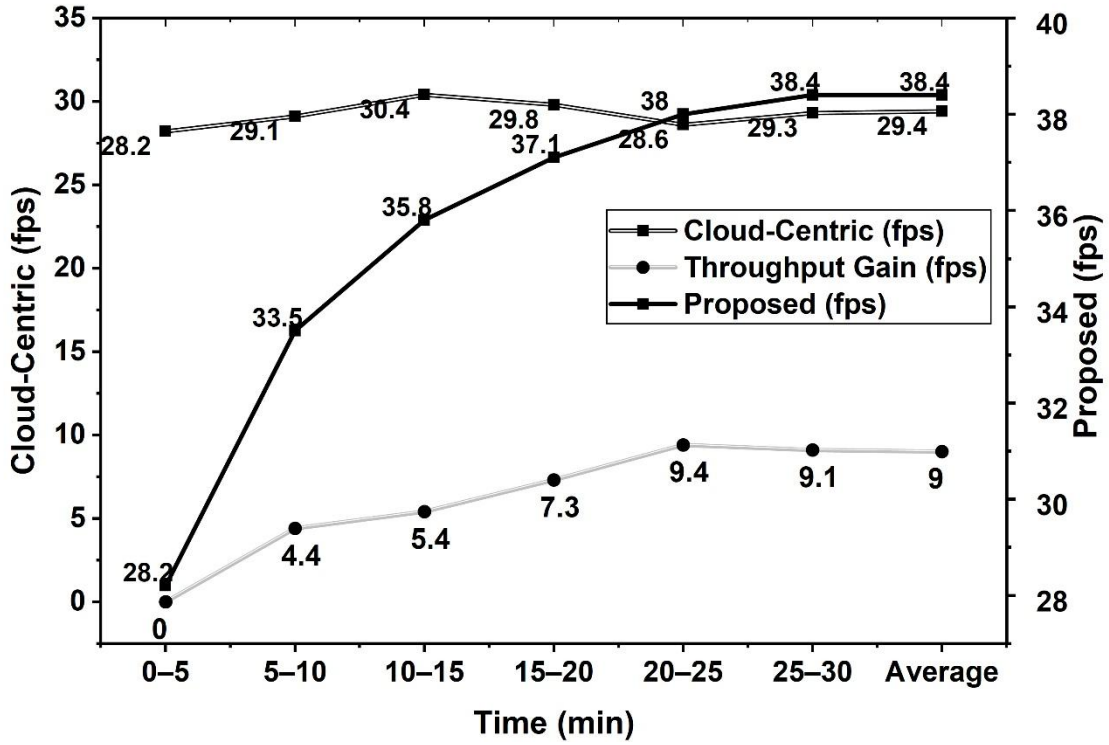

Figure 4: Processing throughput (frames/sec) over a 30-minute evaluation window for cloud-centric and proposed framework architectures.

As shown in figure 4, there is a progressive increase in the framework's throughput, with the increase in throughput accelerating after 10 minutes when the adaptive load balancer came into play, utilising the extra resources to achieve a throughput of 38.4 fps compared with 29.3 fps at minute 30.

5.1.1. Validation of Analytical Models

The analytical formulations presented in Section 3 were validated using experimentally measured system parameters. According to Equation (1), the average edge processing latency was obtained as the sum of decoding (12.4 ms), preprocessing (9.8 ms), inference (41.6 ms), and transmission (9.7 ms) delays, resulting in a total latency of 73.5 ms, which corresponds to the value reported in Table 2. Similarly, Equation (2) was applied using the measured bandwidth utilization values of the cloud-centric architecture (92.1%) and the proposed framework (47.3%), yielding a bandwidth reduction of 48.6%, consistent with the results presented in Table 3. Furthermore, Equation (3) produced an average throughput of 38.4 fps during the 30-minute evaluation period, matching the throughput measurements reported in Table 4. These results demonstrate that the analytical models provide a realistic representation of the observed system behaviour and support the reported performance improvements.

The remaining analytical formulations were also reflected in the experimental observations. Equation (6) was used to model node failure behaviour under the fault-injection scenarios presented in Table 5, while Equation (7) decomposed the average recovery time into failure detection, failover switching, and synchronization stages. Equations (8) and (9) guided workload redistribution by selecting the least-utilized edge node under queue-capacity constraints, contributing to the throughput improvements reported in Table 4. Finally, Equation (10) was used to estimate service availability, yielding a value of 97.1%, consistent with the experimental results reported in Table 6.

5.2. Reliability, Availability, and Detection Performance

Table 5 shows the fault recovery statistics of all four fault injection scenarios. The presented framework showed an average gain of 28.1% in terms of fault tolerance and a reduction in the mean recovery time from 19.0s (cloud-centric approach) to 13.7s. Within 2.1 seconds of detecting failure, on average, the local persistence mode was activated, greatly reducing monitoring gaps during the communications outage. The redundant edge coordination protocol helped the most in terms of node crash recovery, decreasing recovery time from 22.7 to 16.3 seconds (28.2% improvement).

Table 5

Fault Recovery Metrics by Failure Type

Failure Type	Cloud Recovery (s)	Proposed Recovery (s)	Improvement (s)	Improvement (%)	Detection Gap (s)
Network Partition	18.4	13.2	5.2	28.3%	1.8
Node Crash	22.7	16.3	6.4	28.2%	2.4
Packet Loss (30%)	15.2	11.1	4.1	27.0%	1.2
Link Failure	19.8	14.2	5.6	28.3%	1.9
Average	19.0	13.7	5.3	28.1%	1.8

Table 6 shows the service availability and event detection accuracy of four system configurations. The proposed framework achieved 97.1% service availability which is higher than the cloud-centric system (89.4%), edge-only system (93.1%) and federated learning approach (91.6%). An accuracy of 94.3% was achieved in detecting events, which surpassed the accuracy of the cloud-centric baseline of 88.6% and highlighted that local edge inference could ensure good detection accuracy without the need for cloud connectivity.

Table 6

Service Availability and Event Detection Accuracy Comparison

Architecture	Availability (%)	Detection Acc. (%)	F1-Score	Mean MTTR (s)	Downtime/Day (min)
Cloud-Centric Baseline	89.4	88.6	0.881	19.0	15.2
Edge-Only System	93.1	91.4	0.908	15.6	9.9
Federated Learning	91.6	90.2	0.897	17.3	12.2
Proposed Framework	97.1	94.3	0.940	13.7	4.2

The observed improvements arise from three interacting mechanisms. First, local edge inference eliminates repeated transmission of high-volume video streams, directly reducing latency and bandwidth consumption. Second, adaptive workload redistribution prevents computational bottlenecks under varying traffic conditions, leading to sustained throughput improvements. Third, local persistence mode and redundant edge coordination minimize service interruptions during network failures, explaining the higher service availability and reduced recovery times observed in fault-injection experiments. These findings indicate that reliability and performance are mutually reinforcing properties within the proposed architecture rather than competing objectives. The results further demonstrate that cloud–edge collaboration provides greater operational resilience than purely cloud-centric or edge-only deployments.

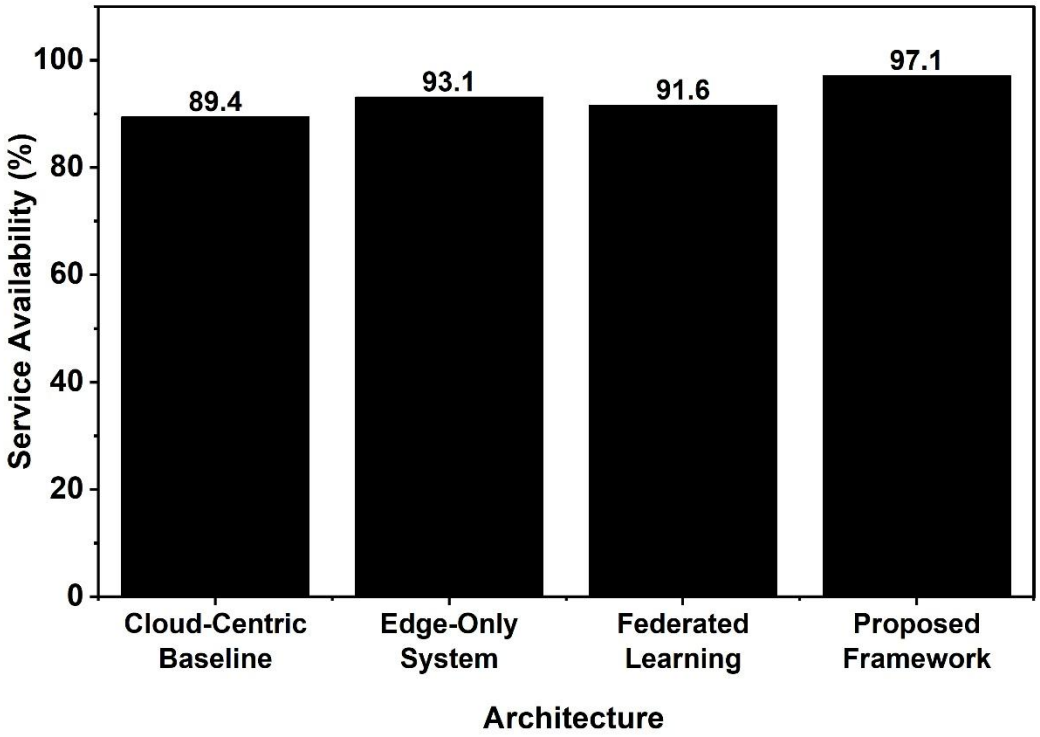

Figure 5: Service availability (%) comparison across cloud-centric, edge-only, federated learning, and proposed framework architectures

As shown in Figure 5, the service availability of the proposed framework was 97.1%, which was higher than the other three comparative architectures, further proving the effectiveness of fault-tolerant edge coordination.

5.3. Comparative Evaluation against Cloud-Centric Architectures

Figure 6 compares the performance of the proposed framework with the baseline architectures across six evaluation metrics. The proposed framework achieved superior performance across all evaluated metrics, including bandwidth reduction (48.6%), throughput gain (26.3%), fault-tolerance improvement (28.1%), service availability (97.1%), and detection accuracy (94.3%). It is observed that the proposed framework achieved superior performance across all evaluated metrics as shown in figure 6 with the best performance of 48.6% in the class Bandwidth reduction, 26.3% in class Throughput. The synergistic improvements by the local stream processing and adaptive load balancing and fault-tolerant coordination, which could not be attained by any single-tier architecture, were achieved. One interesting finding was that the low latency performance (73.5ms), the high availability (97.1%) and high detection accuracy (94.3%) were all achieved together: that the performance and reliability goals were reinforcing goals in the proposed architecture.

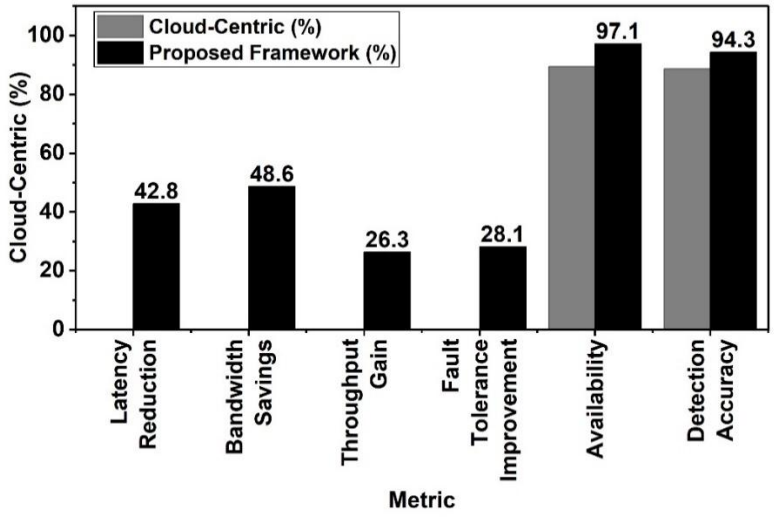

Figure 6: Overall performance comparison between cloud-centric and proposed framework across all six-evaluation metrics. The paired t-test confirmed that the improvements achieved by the proposed framework over the baseline architectures were statistically significant ($p < 0.05$) across all evaluated metrics.

6. Conclusion

This study proposed and evaluated an edge-enabled video surveillance framework integrating local stream processing, adaptive load balancing, and fault-tolerant cloud–edge coordination. The experimental results show that coordinated edge intelligence can help to improve the operation efficiency as well as the system reliability in distributed surveillance environments at the same time. The framework processes the video streams close to the source of the data, minimizing communication overhead and the latency of analytics far from the data source; it also redistributes workloads adaptively to maintain the throughput of video stream processing under different network and computational conditions. Fault-tolerant recovery mechanisms and local persistence mode also help reduce any service interruptions during fault situations, leading to better service continuity and availability. These complementary enhancements suggest that responsiveness and resource efficiency and reliability are all self-reinforcing characteristics of the proposed architecture, and not mutually exclusive goals. The framework's effectiveness as a scalable solution for large-scale IoT-enabled surveillance systems is further supported by the deployment of the system for 30 days, as well as the analysis and validation of the data collected.

6.1 Limitations

While the results are promising, there are some caveats. First, it is an experimental evaluation on a small testbed with 8 edge nodes that may not fully capture the complexity of the large-scale real-world surveillance deployments. Second, the evaluation was based on the VIRAT surveillance data set and synthetic multi-camera video streams, and may not reflect the range of environments, camera setups, and scenarios that are used in practice. Future research is needed to overcome these limitations, both in terms of scale of deployment, wider range of data, and longer periods of operation.

6.2. Future Work

Further studies will be conducted to expand the proposed framework in a number of ways. On the other hand, federated learning mechanisms will enable collaborative model training among the distributed edge nodes without sharing the raw video data with the cloud, which is vital in sensitive surveillance scenarios because of privacy concerns. Second, 5G and beyond-5G network slicing will be investigated as a communication substrate to offer guaranteed latency and bandwidth channels for surveillance streams when there is variable network load conditions.

Data Availability Statement

The VIRAT Video Dataset is publicly available, whereas the synthetic surveillance streams were generated for this study and are not publicly distributed. Experiments were conducted using Python 3.10, PyTorch 2.1, TensorRT 8.6, and a fixed random seed of 42. Sufficient methodological details are provided to support reproducibility.

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COMPARATIVE ANALYSIS OF MODERN GEODETIC SURVEY METHODS IN OPEN PIT MINING: ACCURACY, APPLICABILITY AND TECHNOLOGICAL TRENDS

Kunytska M.
Doctor of Philosophy, Associate Professor, Department of Mine Surveying
Zhytomyr Polytechnic State University, Zhytomyr, Ukraine
Kalchuk S.
PhD, Associate Professor, Department of Mine Surveying
Zhytomyr Polytechnic State University, Zhytomyr, Ukraine
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ABSTRACT

The article presents a comparative analysis of five main geodetic survey methods applied in open pit mining operations: electronic total station surveying, GNSS surveying (RTK/PPK), terrestrial laser scanning (TLS), UAV-based aerial photogrammetry with Structure from Motion processing (UAV+SfM), and radar differential interferometric monitoring. The metrological characteristics and applicability conditions of each method are determined. A classification of methods is proposed and a system of comparative tables and visual charts is developed based on the criteria of coordinate accuracy, productivity, cost-effectiveness, and application domain. Based on multi-criteria analysis (MCA), it is established that the integration of UAV+SfM with PPK and a network of ground control points (GCP) provides an optimal balance between accuracy (15–25 mm) and productivity (up to 3 km²/h) for the majority of mine surveying control tasks at open pit enterprises. The technological development trends of geodetic equipment for open pit mines during 2014–2026 are systematized, and three key tendencies are identified: convergence of methods and sensor integration, automation of data processing, and democratization of UAV technologies.

Keywords: geodetic survey; open pit mining; quarry; UAV; Structure from Motion; terrestrial laser scanning; GNSS; mine surveying; measurement accuracy; multi-criteria analysis.

1. Introduction

Geodetic surveying is an integral component of the technological process of open pit mineral extraction. The safety of mining operations, the efficiency of mining equipment utilization, and the accuracy of extracted raw material accounting directly depend on the quality and timeliness of mine surveying and geodetic measurements. As quarry depths increase, surveying areas expand, and requirements for digital documentation of mining operations grow, the need for a systematic comparison of available geodetic technologies becomes particularly relevant.

During 2014–2026, the range of geodetic methods for open pit operations expanded significantly. Alongside classical approaches - electronic total station surveying and GNSS - terrestrial laser scanning (TLS), UAV-based aerial photogrammetry with Structure from Motion (SfM) algorithms, and radar interferometric monitoring of slope deformations gained widespread adoption. Each technology is based on different physical principles and has its own metrological characteristics, which complicates the reasoned selection of a method for specific production conditions [1, 3].

Significant contributions to the field have been made by researchers from Zhytomyr Polytechnic State University. Kunytska M., Kotenko V. and Piskun I. substantiated the parameters of UAV aerial photography for geodetic support of quarry operations [3]. Yanovych O. and Kotenko V. conducted a comparative assessment of RTK and non-RTK UAV technologies in mine surveying practice [5]. Panasiuk A., Kunytska M. et al. developed a methodology for integrating UAV survey data into the geodetic monitoring system of mine workings [1]. Among international studies, Park S. and Choi Y. systematized the experience of UAV applications in mining from exploration to reclamation [8]. Levytskyi V., Sobolevskyi R. and Korobiichuk V. investigated the application of photogrammetric technologies for controlling the parameters of natural stone block extraction [7].

Despite the large volume of publications, a comprehensive comparative analysis of all current methods from the perspectives of accuracy, productivity, applicability conditions, and technological trends remains insufficiently represented in the scientific literature. A unified scientifically substantiated approach to method selection depending on the specific mine surveying task is also absent.

The aim of this article is the systematization and comparative analysis of modern geodetic survey methods in open pit mining according to accuracy, applicability, and technological trend criteria, as well as the development of practical recommendations for the rational selection of a method depending on the mining conditions.

2. Literature Review

Analysis of scientific publications from 2012 to 2026 demonstrates intensive development of geodetic technologies for open pit mining. The key research direction has been the introduction of UAVs as a multipurpose platform for mine surveying.

Shahmoradi J. et al. conducted a comprehensive review of UAV applications in the mining industry, identifying topographic surveying, volume control, and safety monitoring as priority directions [12]. Park S. and Choi Y. systematized UAV experience from exploration to reclamation and established that UAV survey accuracy with properly placed ground control points is sufficient for most mine surveying tasks [8]. Lee S. and Choi Y. analyzed UAV technology development trends and identified cost reduction and processing automation as the main drivers of mass adoption [13].

Zapico I. et al. demonstrated that optimization of flight routes and GCP density in UAV surveying allows achieving accuracy comparable to ground-based methods for long highwall surveys at open pit mines [14]. Ren H. et al. emphasized the importance of integrating data from various geodetic sensors for comprehensive monitoring of mining areas [15].

Sobolevskyi R., Levytskyi V. and Shlapak V. [10] performed a comparative accuracy assessment of photogrammetric methods and laser scanning for measuring parameters of natural rock separateness and established that TLS outperforms photogrammetry in accuracy at distances exceeding 30 m. Levytskyi V. and Sobolevskyi R. [9] applied digital surface photogrammetry for quality control of decorative stone blocks, confirming the practical effectiveness of the method under quarry conditions.

Among domestic studies, the works of Panasiuk A., Kunytska M. et al. [1] on UAV data integration into geodetic monitoring systems, and the study of Vashchuk O. and Sobolevskyi R. [17] on the methodology for calculating volumes of finished product stockpiles, which is an important mine surveying task at construction material quarries, are noteworthy. Korobiichuk V. et al. [19] investigated the associated extraction of natural stone blocks under quarry conditions. Piskun I., Kotenko V. et al. [18] systematized the technological equipment of mining enterprises, including geodetic instrumentation. Denysiuk O. and Panasiuk A. [2] examined geodetic components as a key element of mining enterprise digitalization in the context of Industry 4.0.

Analysis of publications confirms that no single method is universal, and the choice of technology depends on a combination of accuracy requirements, productivity, accessibility conditions, and available budget. This necessitates the development of a systematic comparative approach using tables and charts.

3. Classification of Geodetic Survey Methods for Open Pit Mining

Based on the analysis of literature sources and mine surveying practice, a classification of geodetic survey methods for open pit mining enterprises has been developed (Table 1). The classification criteria include: physical measurement principle, sensor carrier type, coordinate accuracy range, field productivity, and typical application tasks.

An important methodological note concerns radar monitoring: unlike other methods, it does not measure absolute coordinates of points but rather relative surface displacements in the direction of the Line of Sight (LOS). Therefore, the radar accuracy of 0.1–1 mm is relative and cannot be directly compared with the absolute accuracy of other methods. UAV+SfM is presented in two variants - basic (without correction) and enhanced (with PPK and GCP), since the accuracy difference between them is substantial [1, 3, 5].

Table 1

Classification of geodetic survey methods for open pit mining operations (H - horizontal coordinates, V - vertical coordinates, LOS - Line of Sight)

Method	Physical Principle	Coordinate Accuracy	Productivity	Main Tasks at Quarry
Electronic Total Station	Angular-distance measurements (EDM + coded circle)	3–10 mm abs.	Low (100–300 pts/shift)	Bench and slope surveying; project layout in the field; control and verification measurements
GNSS RTK	Phase pseudorange measurements to satellites with real-time differential corrections	10–15 mm (H) 20–25 mm (V)	Medium (300–500 pts/shift)	Quarry surface surveying; GCP referencing for UAV; volume calculation; profiles
GNSS PPK	Phase measurements with post-processing of differential corrections (no field communication required)	15–25 mm (H) 25–40 mm (V)	Medium (300–500 pts/shift)	Deep quarry surveying; GCP referencing; integration with UAV onboard GNSS
Terrestrial Laser Scanning (TLS)	Laser pulse or phase ranging with angular scanning (up to 1 M pts/min)	2–6 mm abs. (dist. up to 100 m)	High (up to 1 M pts/min)	3D bench models; slope deformation control; exposure passports; precise stockpile volumes
UAV + SfM (basic)	Aerial photogrammetry with Structure from Motion from UAV without PPK	20–50 mm (H) 30–80 mm (V)	High (up to 1–2 km²/h)	Orthophotos; digital elevation model (DEM); dump volumes; reclamation monitoring
UAV + SfM + PPK/GCP	SfM with GNSS kinematic post-processing and/or dense GCP network	15–25 mm (H) 20–40 mm (V)	High (up to 2–3 km²/h)	Precise DEM; mine surveying documentation; extraction volumes; detailed surface monitoring

Radar Monitoring (IBIS / SSR)	Microwave differential interferometry; measures relative LOS displacements	0.1–1 mm rel. (LOS direction)	Continuous (1–5 min cycle)	Continuous real-time monitoring of slope and dump deformations; early landslide warning

4. Comparative Analysis of Accuracy

Accuracy is the key criterion when selecting a geodetic survey method for mine surveying tasks. Regulatory requirements for survey accuracy at open pit mines are defined by the Safety Rules for Open Pit Mining Operations and national standards. As a general rule, the required accuracy for the planned boundary of excavation is ±50 mm, for the height control of benches ±30 mm, and for volume calculation ±(1–3)% of total volume.

Table 2 provides a detailed comparison of accuracy characteristics of the methods under various application conditions. The data are based on research results [1, 3, 5, 7, 9, 10, 14] and technical specifications of leading manufacturers (Leica Geosystems, Trimble, DJI Enterprise, IDS GeoRadar).

Table 2

Comparison of accuracy characteristics of geodetic survey methods (△ - partial compliance for large flat areas; LOS - Line of Sight; H - horizontal; V - vertical)

Method	Horizontal Accuracy (mm)	Vertical Accuracy (mm)	Accuracy Type	Compliance with Regulatory Requirements
Total Station (1″, S≤200 m)	1.5–3.5	2–5	Absolute	✓ Full compliance
Total Station (1″, S≤500 m)	3.5–8	5–12	Absolute	✓ Full compliance
GNSS RTK (CORS network)	10–15	20–25	Absolute	✓ Full compliance
GNSS PPK	15–25	25–40	Absolute	✓ Full compliance
TLS (distance up to 50 m)	2–4	3–5	Absolute	✓ Full compliance
TLS (distance 50–150 m)	4–8	5–10	Absolute	✓ Full compliance
UAV+SfM (no PPK, no GCP)	40–80	60–120	Absolute	△ Partial (flat terrain only)
UAV+SfM (5–7 GCP/km²)	20–40	30–60	Absolute	✓ For volume calculation
UAV+SfM+PPK (1–2 GCP/km²)	15–25	20–40	Absolute	✓ Full compliance
Radar IBIS (LOS displacement)	-	0.1–1	Relative (LOS)	✓ Deformation monitoring

Analysis of Table 2 leads to the conclusion that all considered methods, when properly applied, meet the regulatory accuracy requirements for mine surveying. The exception is UAV+SfM without corrective measures (GCP or PPK) for vertical accuracy requirements better than ±50 mm. Radar monitoring uniquely enables detection of slope displacements below 1 mm - a capability unachievable by any other method considered.

Figure 1 presents a structured comparative assessment of typical horizontal coordinate accuracy for each method under optimal application conditions. Accuracy level and trend relative to the previous row are indicated.

Method	Accuracy Level	Typical RMSE (mm)	Trend vs. Previous	Note
Total Station (200 m)	Very High	3	-	Reference level
GNSS RTK	High	10–15	↓ lower	Satellite-dependent
GNSS PPK	Moderate–High	15–25	↓ vs. RTK	No real-time link needed
TLS (dist. ≤50 m)	Very High	2–4	↑↑ vs. PPK	Angle of incidence ≤60°
TLS (dist. 50–150 m)	High	4–8	↓ vs. TLS 50m	Acceptable for bench control
UAV+SfM (no GCP/PPK)	Low	40–80	↓↓	Dome effect; not recommended
UAV+SfM+PPK/GCP	Moderate–High	15–25	↑↑ vs. basic	Optimal cost/accuracy ratio
Radar IBIS (LOS)	Exceptional*	<1	* relative	Relative LOS displacement only

*Figure 1 - Comparative assessment of horizontal coordinate accuracy of geodetic survey methods (typical RMSE under optimal conditions; ↑ higher accuracy, ↓ lower accuracy vs. previous row; * radar measures relative LOS displacement, not absolute coordinates)*

5. Comparative Analysis of Productivity and Cost

Alongside accuracy, productivity and cost are decisive practical criteria when selecting a geodetic survey method. For open pit mining enterprises where survey areas can reach several square kilometres and survey frequency may be once or twice monthly, these parameters are often determining factors.

Table 3 presents a comparison of methods by productivity and cost indicators. Equipment costs are given in US dollars as of 2024, based on data from official distributors and international marketplaces. The cost of one survey of 1 km² is calculated accounting for equipment depreciation, labour costs, and consumables.

Table 3

Comparison of productivity and cost of geodetic survey methods (data as of 2024; survey cost includes equipment depreciation and labour)

Method	Productivity (1 km², hrs)	Equipment Cost, USD	Survey Cost 1 km², USD	Operators Required
Total Station	8–16	5,000–25,000	150–400	1–2
GNSS RTK	3–6	8,000–30,000	80–200	1
GNSS PPK	4–8	10,000–35,000	100–250	1
TLS	1–3	40,000–120,000	300–800	1–2
UAV+SfM (basic)	0.5–1.0	3,000–15,000	50–150	1
UAV+SfM+PPK/GCP	0.3–0.7	8,000–25,000	80–200	1–2
Radar IBIS/SSR	Continuous	150,000–500,000	800–2,000/mo.	1

Data from Table 3 confirm that UAV+SfM is the most cost-effective method for mass surveying of large areas. The cost of one survey of 1 km² is 2–5 times lower than total station surveying, and 6–16 times lower than TLS. At the same time, TLS remains irreplaceable for tasks requiring high point density and 3D model accuracy. Radar monitoring is the most capital-intensive method but has no alternative for continuous real-time slope deformation monitoring tasks.

Figure 2 presents a structured comparative assessment of field productivity for each method when surveying an area of 1 km². Productivity level and trend relative to the previous row are indicated.

Method	Productivity Level	Time for 1 km² (hrs)	Trend vs. Previous	Note
Total Station	Low	8–16	-	Reference level; detailed tasks
GNSS RTK	Moderate	3–6	↑↑ vs. TS	Efficient for profile surveys
GNSS PPK	Moderate	4–8	≈ RTK	No real-time connection required
TLS	High	1–3	↑↑ vs. GNSS	High point density; multi-station setup
UAV+SfM (basic)	Very High	0.5–1.0	↑↑↑ vs. TLS	Best for large area coverage
UAV+SfM+PPK/GCP	Very High	0.3–0.7	≈ basic	GCP setup adds minor field time
Radar IBIS/SSR	Continuous	Continuous	N/A	24/7 automated monitoring; no field surveys

Figure 2 - Comparative assessment of field productivity of geodetic survey methods for a 1 km² survey area (↑ higher productivity, ↓ lower productivity vs. previous row; radar monitoring excluded from time comparison as a continuous automated system)

6. Multi-Criteria Analysis and Method Selection Recommendations

For an integral evaluation of methods, the Multi-Criteria Analysis (MCA) approach was applied, widely used in mining practice for the selection of technological solutions [2, 8]. Evaluation was performed across nine criteria on a five-point scale (5 - best performance, 1 - worst). The scale was formed on the basis of: analysis of technical specifications of equipment from leading manufacturers; data from scientific publications [1, 3, 5, 7, 8, 10, 12, 13, 14, 15]; and regulatory documents.

Table 4

Multi-criteria comparative assessment of geodetic survey methods (5-point scale; * - radar evaluated only on criteria 2, 5, 6, 7, 8, 9 as it does not measure absolute coordinates)

Evaluation Criterion	Total Station	GNSS RTK	TLS	UAV +SfM	Radar IBIS
1. Absolute coordinate accuracy	5	3	5	3	-
2. Survey productivity	2	3	4	5	5
3. Equipment availability and cost	5	5	2	4	1
4. Cost-effectiveness (per 1 km²)	3	4	2	5	1
5. Effectiveness in deep quarries	5	2	5	3	5
6. Independence from weather conditions	4	4	3	2	5
7. 3D modelling capability	2	2	5	5	2
8. Continuous deformation monitoring	1	1	2	1	5
9. Ease of data processing	5	5	3	3	3
Total score (max = 45)	32	29	31	31	27*

Analysis of Table 4 yields the following conclusions. The total station achieved the highest total score (32) due to its combination of accuracy, availability, and ease of data processing. TLS and UAV+SfM received equal scores (31) but for fundamentally different criteria: TLS excels in accuracy and 3D modelling,

UAV+SfM - in productivity and cost-effectiveness. GNSS RTK is the most balanced solution for routine surveying. Radar monitoring is a specialized method with no alternative for continuous slope stability observation tasks.

Based on the obtained results, practical recommendations for method selection depending on the mine surveying task were formulated (Table 5).

Table 5

Practical recommendations for geodetic survey method selection by mine surveying task

Mine Surveying Task	Recommended Method	Alternative
Layout of designed bench boundary in the field	Total Station	GNSS RTK
Current quarry survey (volume, DEM, plan)	UAV+SfM+PPK/GCP	GNSS PPK (profiles)
Bench and exposure passport (3D model)	TLS	UAV+SfM
Slope stability control (single survey)	TLS	Total Station (profiles)
Continuous slope deformation monitoring	Radar IBIS/SSR	TLS (repeated cycles)
Reclaimed area surveying	UAV+SfM+PPK	GNSS RTK
Ground Control Point (GCP) referencing	GNSS RTK	Total Station
Monthly extraction volume accounting	UAV+SfM+PPK/GCP	GNSS PPK

7. Technological Development Trends in Geodetic Methods for Open Pit Mines (2014–2026)

Analysis of publication dynamics and equipment technical specifications reveals three defining technological tendencies in the development of geodetic methods for open pit mines.

The first tendency is method convergence and sensor integration. Modern geodetic solutions are hybrid systems: UAV + GNSS (PPK) + photogrammetry (SfM), TLS + GNSS, mobile scanning (SLAM + IMU + lidar). This allows compensating for the limitations of individual methods and achieving a synergistic effect of accuracy and productivity [1, 3]. Panasiuk A., Kunytska M. et al. [1] demonstrated the practical effectiveness of integrating UAV surveying with ground geodetic monitoring for comprehensive control of mining workings.

The second tendency is automation of data processing. Development of SfM algorithms (Agisoft Metashape, Pix4D, OpenDroneMap), cloud processing platforms, and machine learning methods reduces the time from flight to finished product (DEM, volume, report) from several days to 2–4 hours. Denysiuk O. and Panasiuk A. [2] consider the geodetic component as a key element of mining enterprise digitalization within the context of Industry 4.0.

The third tendency is democratization of UAV technologies. The cost of an industrial UAV+SfM kit decreased from 50,000–100,000 USD in 2014 to 5,000–20,000 USD in 2024, while equipment accuracy and reliability significantly improved. Baranovskyi A. and Sobolevskyi R. [16] recorded the beginning of mass practical use of copters at Ukrainian mining enterprises in 2020. Panasiuk A. and Polishchuk D. [4] substantiated criteria for selecting optimal UAV instruments for mine surveying.

The chronology of key technological events is presented in Table 6.

Table 6

Chronology of key technological events in the development of geodetic methods for open pit mining (2012–2026)

Period	Key Events and Studies
2012–2013	Digital surface photogrammetry for stone quarries [9]. Methodology for stockpile volume calculation [17]
2014–2015	Accessible multirotor UAVs (DJI Phantom). Start of SfM in mining. First UAV mining publications [13]
2016	TLS vs. photogrammetry comparison for rock discontinuities [10]. Diamond wire stone extraction technology [11]
2018	Quarry parameter optimization via photogrammetry [7]. First UAVs with onboard RTK module (DJI Phantom 4 RTK)
2019–2020	Comprehensive UAV mining reviews [8, 12]. Long highwall survey methodology [14]. Copters at Ukrainian mining enterprises [16]
2021–2022	RTK/PPK comparative analysis for mine surveying [5]. Mining enterprise digitalization (Industry 4.0) [2]. Natural stone block extraction [19]

2023–2024	UAV instrument selection for mine surveying [4]. AI in point cloud processing. Real-time cloud platforms
2025–2026	UAV integration into geodetic monitoring systems [1]. UAV survey parameters for quarries [3]. Autonomous UAV systems

Ren H. et al. [15] forecast further development towards autonomous UAV systems with onboard artificial intelligence for real-time anomaly and deformation detection, as well as integration of geodetic data into quarry digital twin systems. Denysiuk O. and Panasiuk A. [2] consider these trends as consistent with the overall digitalization vector of mining enterprises under Industry 4.0 conditions.

8. Conclusions

1. A classification of five main geodetic survey methods for open pit mining has been developed and substantiated (Table 1). The metrological characteristics of methods have been specified: TLS accuracy (2–6 mm) is stated for distances up to 100 m; UAV+SfM+PPK/GCP accuracy (15–25 mm horizontal, 20–40 mm vertical) - for an optimized flight scheme with a GCP network; radar monitoring accuracy (0.1–1 mm) is relative in the LOS direction and cannot be directly compared with the absolute accuracy of other methods.

2. Comparative accuracy analysis (Table 2) showed that all considered methods, when properly applied, comply with regulatory requirements for mine surveying accuracy. The UAV+SfM mode without corrective measures is insufficient for vertical surveying with accuracy requirements better than ±50 mm. Integration of PPK and GCP fundamentally improves the result and makes the method fully suitable for most mine surveying tasks.

3. Productivity and cost analysis (Table 3) confirmed that UAV+SfM is the most cost-effective method for mass large-area surveying: the cost of one survey of 1 km² is 2–5 times lower than total station surveying. Radar monitoring is the most capital-intensive but the only method for continuous real-time slope deformation monitoring.

4. Multi-criteria analysis (Table 4) established that no single method is universal. The total station remains irreplaceable for detailed measurements and project layout. UAV+SfM is optimal for mass surveying and DEM construction. TLS provides the highest point density and 3D model accuracy. Radar IBIS has no alternative for early landslide warning. Practical recommendations for method selection (Table 5) enable the reasoned choice of technology for specific mine surveying tasks.

5. Three key technological trends of 2014–2026 have been systematized: convergence of methods and sensor integration; automation of data processing; and democratization of UAV technologies (5–10-fold cost reduction over 10 years). A promising direction is the development of quarry digital twins based on the integration of geodetic data from all considered methods into a unified geospatial platform within the Industry 4.0 framework.

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METHODS FOR PLANNING THE USE OF OPTICAL INSTRUMENTS FOR THE OBSERVATION OF SPACE OBJECTS

Myklukha V.
Associate Professor, Department of Space Reconnaissance, PhD
Korolov Zhytomyr Military Institute
Khimchyk A.
student
Lviv Polytechnic National University
DOI: 10.5281/zenodo.21364235

ABSTRACT

This article examines current issues relating to the planning of the deployment of optical means of observing space objects in space surveillance systems. An analysis is carried out of the factors influencing the operational effectiveness of ground-based optical systems, including the orbital characteristics of space objects, astronomical and meteorological observation conditions, the technical capabilities of optical systems, time constraints, and the required frequency of orbital data updates.

A methodology for planning the use of optical systems is proposed, based on determining a rational observation frequency for space objects, taking into account the rate at which errors in predicting their motion parameters accumulate the priority of the objects under surveillance, and the capabilities of the network of optical stations. The methodology involves the adaptive formulation of an observation plan through the optimal allocation of resources amongst space objects of different categories, thereby ensuring that the required accuracy of the space object catalogue is maintained whilst minimizing the load on the observation equipment.

It has been shown that the use of the proposed approach helps to speed up the updating of orbital information, improve the quality of space situational awareness forecasting, increase the efficiency of optical means, and ensure the timely detection of changes in the motion parameters of space objects. The practical implementation of this methodology can be utilized to improve the algorithms governing the operation of automated space surveillance systems and to enhance the information support provided to space situational awareness centres.

Keywords: space surveillance, optical observation systems, space objects, mission planning, optimization, fields of view, satellite monitoring.

Relevance of the topic.

The rapid increase in the number of spacecraft, the deployment of multi-satellite low-orbit commercial and military constellations, and the growing volume of space debris are placing new, stringent demands on space situational awareness systems. The primary means of obtaining high-precision visual and coordinate-time data on the space situation are optical systems (both ground-based and airborne). However, the effectiveness of their use is significantly limited by the dynamic nature of the target environment, meteorological conditions, the background-to-target ratio, and the limited duration of object visibility. This creates an urgent need to develop and refine the scientific and methodological framework for the automated planning of their operations.

The aim of this article is to develop a comprehensive methodology for the dynamic planning of the deployment of optical observation systems, which enables the maximization of the number of space objects monitored and the accuracy of determining their motion parameters under stringent time and resource constraints.

Presentation of the main material.

The effective use of ground-based optical systems for observing space objects depends to a large extent on the quality of the planning for their deployment. Unlike the passive observation of stationary objects, the monitoring of spacecraft is characterized by a dynamic environment, limited visibility windows, dependence on meteorological conditions (Fig. 1), and the technical characteristics of specific observation systems. In this regard, the task of planning the deployment of optical observation systems requires a formalized approach.

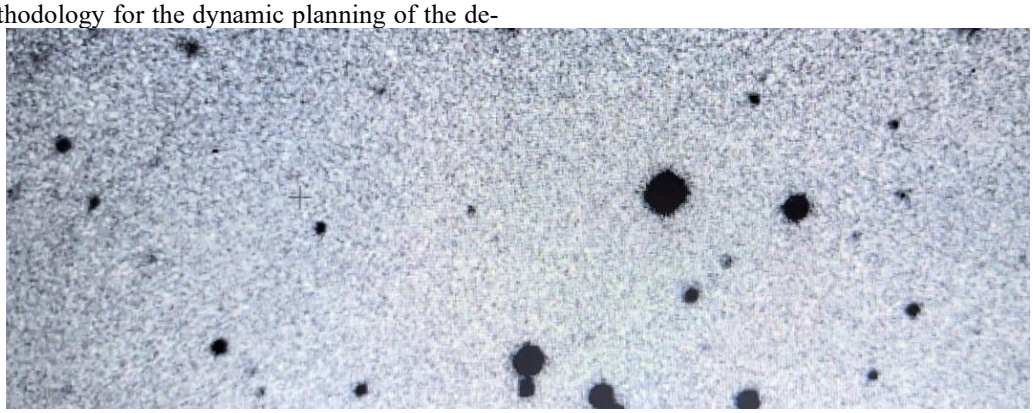

Figure 1 – Telescope observations in cloudy conditions

This paper examines the problem of allocating available optical surveillance resources amongst a set of space objects to be monitored, taking into account technical, temporal and external constraints.

Let the set of available optical resources be defined as:

$$T = \{t1, t2, \ldots, tn\}, \quad (1)$$

where t_i – a separate ground-based optical surveillance system.

A multitude of space objects that need to be monitored:

$$S = \{s_1, s_2, \ldots, s_m\}, \quad (2)$$

where s_j – a separate space object.

Each observation asset is characterized by the following parameters:

• geographical coordinates of its location;
• technical condition;
• permissible observation sector;
• minimum elevation angle;
• maximum tracking speed;
• current operational status.

Each space object is characterized by:

• orbital parameters;
• predicted position over time;
• observation priority;
• available observation time windows;
• illumination conditions.

The aim of the planning process is to create a matrix of assignments:

$$X = [x_\{ij\}], \quad (3)$$

where a matrix element is defined as follows:

$$x_{ij} \in \{0,1\}, \quad (4)$$

where:

x_{ij}=1 – if the optical instrument ti is intended for observing an object sj;

x_{ij}=0 – otherwise.

At any given moment, each observation device can track only one object:

$$\sum_{j=1}^{m} x_{ij} \leq 1, \quad (5)$$

An appointment can only be made provided that the vehicle is technically fit:

$$A_i \in \{0,1\}, \quad (6)$$

where:

A_i=1 – the device is in working order;

A_i=0 – product unavailable.

Another essential condition is that the space object must be geometrically accessible for observation:

$$V_{\{ij\}} \in \{0,1\}, \quad (7)$$

where:

V_{ij}=1 – the object is visible;

V_9=0 – object is unavailable.

Weather conditions are of critical importance for optical systems; therefore, a meteorological suitability factor is also taken into account:

$$V_{\{ij\}} \in \{0,1\}, \quad (8)$$

where:

W_i=1 – weather conditions allow for observations;

W_i=0 – observation is not possible.

The objective function of the problem is to maximise the efficient use of available resources:

$$F = \sum_{i=1}^{n} \sum_{j=1}^{m} P_j \cdot V_{ij} \cdot W_i \cdot x_{ij}, \quad (9)$$

where:

F– the overall effectiveness of the plan drawn up;

P_j – object priority;

V_{ij} – geometric accessibility;

W_i – suitability of weather conditions;

x_{ij} – appointment.

Thus, the problem boils down to the optimal allocation of observation resources amongst available targets, subject to a set of constraints.

A distinctive feature of this problem is its dynamic nature. The orbital parameters of space objects change, weather conditions may deteriorate or improve, and individual observation assets may temporarily become inoperable. This makes static planning impracticable and necessitates the development of an adaptive approach capable of carrying out the rapid reallocation of resources.

Thus, this paper sets out a planning methodology comprising the following stages:

Stage 1. Initialization

The following are loaded: the current catalogue of objects (in the example considered – 20 spacecraft); the parameters of four optical instruments (located in the Kyiv, Zakarpattia, Zhytomyr and Odesa regions); the observation schedule (3 days); current weather conditions and the forecast.

Stage 2. Calculation of visibility windows

For each pair (object, telescope), all visibility windows are calculated for the observation schedule. This involves the use of orbital propagation models (e.g. SGP4/SDP4 for TLE elements) and the calculation of illumination conditions. The result is a set of time intervals $[t_{start}, t_{end}]$ during which observation is technically feasible.

Stage 3. Priority calculation

For each object, the current observation priority $P_i(t)$ is calculated. It is determined taking into account:

– the current forecast error $\sigma_i(t)$ – the greater the error, the higher the priority;

– the class and type of object (operationally important objects are assigned a higher base priority);

– the time until the first available visibility window – if the nearest window is closing rapidly, the priority is increased;

– signs of instability (previously detected deviations from the forecast, reports of maneuvers).

Stage 4. Allocation of the initial schedule

Each telescope is assigned a group of objects for routine monitoring. In the base scenario, with 20 objects and 4 telescopes, each telescope is assigned 5 objects. The allocation takes into account the geometric arrangement of the telescopes: each telescope receives objects for which it has the greatest number or quality of visibility windows.

Stage 5. Monitoring of conditions and reallocation

The system continuously monitors: weather conditions and the availability of each telescope; the progress of scheduled observations; and current forecast errors for all objects. Should one of the telescopes become unavailable (due to weather conditions, technical problems or a threat arising from military action), its targets are automatically reallocated amongst the other telescopes in the network.

During reallocation: targets are assigned to the telescope with the best visibility window for that target in the near future; reallocated targets are given higher priority to expedite the missed observation.

Stage 6. Carrying out observations and updating orbital parameters

Telescopes carry out observations in accordance with the current schedule. After each successful measurement: the orbital state of the relevant object is updated (orbital elements are refined); the time since the last observation is reset to zero; the forecast error is recalculated; and the priority of the current observation is removed.

Stage 7. Adaptive correction of observations

After each observation cycle (or upon receipt of new information), the algorithm updates the schedule for the next time interval. This allows the actual state of the system to be taken into account and enables a rapid response to changes.

Stage 8. Completion of observation planning and rescheduling

Upon completion of observation planning (3 days), a summary report is generated on the observations carried out, the quality of the data obtained and the current status of the catalogue. On this basis, a plan is drawn up for the next planning period.

The approach to observation planning that has been developed can be applied within the broader context of Space Situational Awareness (SSA) systems. Such systems are designed to comprehensively monitor near-Earth space, detect potential threats and ensure the safe operation of space assets.

Within the framework of SSA, optical instruments perform a number of key functions: detecting new objects (including debris from in-orbit break-ups or anti-satellite tests); maintaining an up-to-date orbital catalogue through regular measurements; assessing the risk of collisions (conjunction analysis); detecting and monitoring spacecraft maneuvers; and observing break-up events.

To effectively integrate the developed approach into the SSA system, it is necessary to combine optical and radar means (to ensure round-the-clock monitoring), automated orbital data processing systems and object catalogue databases. Another important component is a system for exchanging data with international partners and access to global catalogues of spacecraft from the Russian Federation and other states (for example, the catalogue of the US 18th Space Wing and the EU's ExoMet/EUSST catalogue).

Conclusions and prospects for further research.

This article examines the main approaches to planning the use of optical instruments for observing space objects with a view to ensuring the effective functioning of the space surveillance system. The analysis carried out has shown that the effectiveness of ground-based optical systems is largely determined by the soundness of observation planning, which must take into account the orbital characteristics of space objects, the conditions of their optical visibility, the technical capabilities of the observation systems, meteorological factors and the permissible intervals between observation sessions.

The proposed methodology for planning the use of optical means is based on a comprehensive assessment of the priority of space objects, the predicted change in the accuracy of orbital information, and the available resources of the observation network. Unlike approaches that use fixed operating schedules, the proposed methodology involves the adaptive formulation of an observation plan depending on the current state of the space situation and the dynamics of the accumulation of orbit prediction errors.

A promising area for further research is the development of a mathematical model for the adaptive scheduling of an optical station network, utilizing multi-criteria optimization methods and elements of artificial intelligence. This approach will make it possible to automate the process of drawing up observation plans, take into account changes in the space environment in real time, and improve the efficiency of automated space surveillance systems in the face of a constantly growing number of space objects and an increasing load on observation assets.

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PROTECTING PILOT COGNITION: WORKLOAD MANAGEMENT IN AI-AUGMENTED COCKPITS

Nicolas J.L.
Captain, France
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ABSTRACT

Cognitive overload in commercial aviation crews has contributed to fatal loss-of-control accidents in which degraded decision-making, not mechanical failure, was the proximate cause. Existing cockpit monitoring systems based on threshold alert logic detect behavioral consequences of overload, producing alert latencies that consistently exceed the window available for effective intervention. This article presents and evaluates a dual-path neuroadaptive cognitive monitoring framework that fuses electroencephalographic spectral features, heart rate variability indices, and galvanic skin response through a combined LSTM and SVM classifier architecture to achieve real-time three-level pilot cognitive state discrimination. The framework couples the classifier output to a graded cockpit intervention module governed by per-pilot calibrated thresholds and a hysteresis-based authority recovery protocol. Tested on 24 licensed commercial pilots across 144 high-fidelity A320 simulator sessions, the dual-path system achieved a three-class weighted F1 of 0.851, a critical overload recall of 83.1%, and a median detection latency of 7.3 seconds, outperforming an EEG-only threshold classifier by 22.2% (weighted F1) and a rule-based EICAS-modeled system by 31.4 percentage points in critical event recall under identical test conditions.

Keywords: cognitive workload; adaptive automation; neuroadaptive systems; pilot monitoring; electroencephalography; human-autonomy teaming; situation awareness; aviation safety.

Between 2002 and 2011, eighteen loss-of-control accidents in commercial aviation caused approximately 1,493 fatalities, with post-incident analysis consistently implicating degraded decision-making under acute cognitive overload as the proximate cause, not technical system failure (Endsley, 1995). The Air France 447 accident makes the failure mode concrete: autopilot disengagement following pitot tube icing produced a workload spike that exceeded the crew's capacity to integrate conflicting instrument readings within the available response window, a breakdown at what Parasuraman et al. (2010) classify as the information analysis stage of human-automation interaction, where no currently certified cockpit system provides real-time adaptive support. Cockpit automation was designed to reduce physical workload, not to monitor or respond to the cognitive state of the pilot managing it.

Threshold-based alert systems, including EICAS logic derived from population norms, trigger only after a behavioral or physiological parameter breaches a fixed limit, by which point cognitive degradation has already progressed to a state that measurably impairs decision-making. The single-modality EEG classifier reaches a weighted F1 ceiling of approximately 0.693 under active flight simulation conditions, a ceiling imposed by the inherent ambiguity of the signal: frontal theta power elevation is produced both by genuine cognitive overload and by electromyographic contamination from temporalis and frontalis muscles during the high-communication flight phases where accurate classification matters most. Among the 152 empirical studies reviewed by O'Neill et al. (2022), every adaptive automation system that responds to detected operator state does so at a fixed, binary transition point, producing mode confusion workload at the boundary, with no reviewed system combining multimodal biosignal fusion with a hysteresis-governed authority transfer protocol.

Literature Review

The foundational human factors literature was constructed around an epistemic commitment that renders a real-time measurement model unnecessary by design. Endsley (1995) defines situational awareness as a property of the operator's mental model of flight state, validated through SAGAT freeze probes and post-trial debriefs: instruments that interrupt the task they assess and cannot track state transitions at the timescale of an unexpected automation failure. Parasuraman et al. (2010) formalized four stages of human-automation interaction but operationalized each through discrete performance outcomes, yielding accurate post-hoc attribution of failure type with no basis for intervention before the failure completes. Wickens et al. (2021) extended multiple resource theory to predict dual-task interference from structural task properties, generating design heuristics for cockpit layout that treat attention as a function of task demand, which forecloses any account of within-individual capacity variation across a flight shift. These frameworks were purpose-built for accident investigation, training design, and system evaluation, domains for which retrospective validity is sufficient and prospective measurement is irrelevant.

Subjective and behavioral workload instruments fail under time pressure through a mechanism more specific than low temporal resolution. Hart and Staveland (1988) designed the NASA-TLX for post-task administration, validating its six-dimensional structure under conditions stable enough for retrospective rating; deploying it prospectively would require pilots to allocate attentional resources to self-assessment at precisely the moments when those resources are most depleted by the primary task. Cummings (2004) demonstrated that automation bias, the tendency to accept incorrect automated recommendations without seeking contradictory information, peaks at decision cycle times below approximately 15 seconds: the same condition that precludes deliberate workload self-report.

Physiological monitoring converged on EEG-based workload classification as the most tractable real-time approach, but a systematic confound runs through the high-performing studies: nearly all classifiers were trained and tested within the same task modality. Feltman et al. (2021) showed this is consequential: auditory and visual task demands produce distinguishable spectral EEG signatures, which directly undermines any classifier trained on visually dominant simulator tasks and deployed in operational environments combining continuous instrument monitoring with high-frequency ATC communication. Aricò et al. (2016) demonstrated that a passive BCI achieves sufficient reliability to trigger adaptive automation in realistic ATC separation scenarios, but within a single operator task modality and without testing generalization across abrupt workload transitions of the kind produced by unexpected automation failure. Klaproth et al. (2020) provided the most operationally specific individual-level evidence: an ACT-R cognitive model augmented with EEG data achieved 87% accuracy in representing individual pilots' responses to cockpit alerts, against 72% for a normative model without physiological input, a 20.8 percentage point gap that directly quantifies the classification cost of substituting a population mean for individual physiological state. The limitation this group shares is the absence of a validated multi-modality fusion protocol under realistic artifact conditions, embedded within an authority-transfer framework that accounts for the workload the transfer itself generates.

Parasuraman and Manzey (2010) provide the most mechanistically complete account of what sustained high-reliability automation does to operator attention: detection rates for automation anomalies reach 50% failure when operators manage consistently reliable systems under competing task demands, because attentional resources withdraw from the monitored system as reliability increases. For a neuroadaptive architecture, this finding is structurally uncomfortable: increasing automation level in response to detected overload resolves the immediate workload peak by establishing precisely the conditions, sustained automated reliability and reduced manual engagement, that drive the subsequent vigilance decrement the system has no mechanism to detect. O'Neill et al. (2022) documented a parallel trade-off at the transparency level, where higher autonomous agent transparency clarifies system reasoning at the cost of workload increase during the high-demand phases when transparency is most needed.

Method

Three functional layers constitute the closed-loop neuroadaptive control architecture. The acquisition layer collects continuous biosignals from a wearable sensor suite embedded in standard pilot equipment: dry frontal and temporal EEG electrodes capture theta-band power (4 to 8 Hz) as an index of sustained attentional demand and alpha-band suppression (8 to 13 Hz) as an index of cognitive engagement; a photoplethysmographic wrist sensor derives HRV indices, SDNN and the LF/HF ratio, reflecting autonomic load and sympathetic dominance; and a skin conductance sensor captures electrodermal activity as a phasic index of acute arousal. The classification layer runs two parallel paths: a primary LSTM model processes a 10-second rolling window of multimodal feature vectors for high-specificity state estimation, and a parallel SVM classifier processes a 2.5-second window restricted to HRV and EDA for low-latency alerting, trading specificity for response speed. Figure 1 illustrates the full processing pipeline from raw sensor input through the dual-path classifier to graded cockpit intervention.

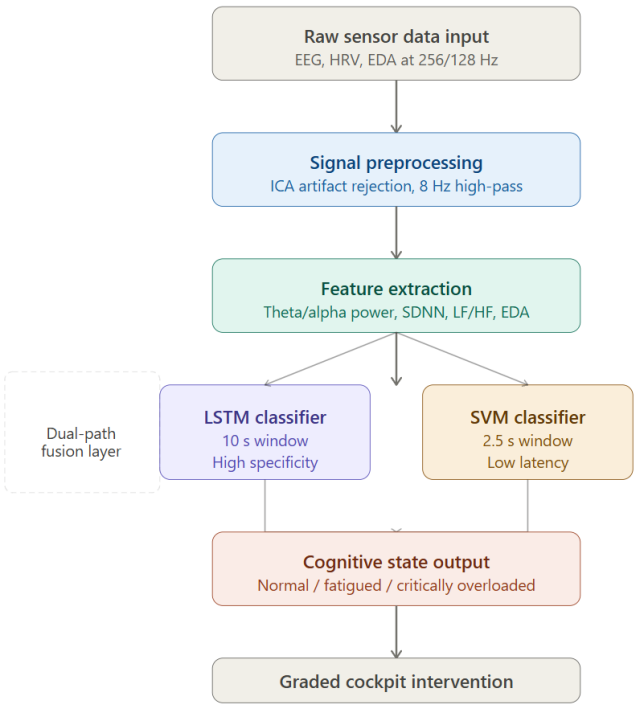

Figure 1. Cognitive load processing pipeline: from multimodal biosignal acquisition through dual-path classification to graded cockpit intervention

Preprocessing incorporates an EMG artifact rejection module using a temporalis reference electrode and independent component analysis to remove contamination in the 20 to 45 Hz range, which overlaps the upper theta and beta bands under standard 8 Hz high-pass filtering. Per-pilot baseline calibration is performed during a 5-minute straight-and-level cruise segment at session start, anchoring HRV LF/HF and EDA tonic level references to each pilot's operational resting state. For pilots exhibiting resting LF/HF ratios above 3.8, indicating constitutive sympathetic dominance that eliminates the HRV channel's discriminative contribution, the model reduces to a two-feature input of EEG theta power and phasic EDA amplitude.

Testing used a high-fidelity A320-type fixed-base flight simulator with a 220-degree horizontal field-of-view visual system and a Stewart platform motion system. Twenty-four licensed commercial pilots, mean flight hours 4,847 (SD 1,203), all holding valid A320 type ratings, completed six simulator sessions each, producing 144 sessions at a mean duration of 47 minutes. Four standardized flight phases were administered in counterbalanced order: level cruise (low cognitive load), approach with single engine inoperative (moderate load), go-around following an unstabilized approach (high load), and unexpected dual-channel autopilot disconnect at decision height (critical load). The critical load scenario was embedded at an unpredictable point within each session to preserve ecological validity. EEG was recorded continuously at 256 Hz; HRV and EDA channels at 128 Hz. Session data were preprocessed offline to establish baseline parameters, then processed in real time through the embedded pipeline during the session.

Four evaluation metrics were applied. Weighted F1 score, the harmonic mean of precision and recall weighted by class frequency, measured three-class state discrimination (normal, fatigued, critically overloaded). Critical overload event-level recall measured the proportion of ground-truth critical events for which the system issued an alert within 30 seconds of event onset. Median detection latency was measured from physiological signal onset, the first sample exceeding 1.5 SD from baseline in any two input channels simultaneously, to the first stable three-window classification flag. PDT error rate, missed target detections per 10-minute flight segment, served as the attentional capacity proxy during intervention condition comparisons. All system comparisons were enforced at a fixed false-positive rate of 0.08 events per flight hour through classifier decision threshold adjustment.

Results

Across all 144 sessions under the conditions specified in the Experimental Setup, the LSTM-SVM ensemble achieved a three-class weighted F1 of 0.847, tested against two explicit baselines on the same sensor hardware, the same preprocessing pipeline, and the same session data: the EEG-only threshold classifier (weighted F1 of 0.693) and the rule-based system modeled on EICAS alert logic (critical overload recall of 47.2% at 0.08 false positives per flight hour). The 22.2% F1 improvement over the EEG-only classifier concentrates in the critical load tier because the HRV channel's LF/HF ratio begins shifting 15 to 20 seconds before EEG theta power crosses a discriminative threshold in high-load scenarios, giving the LSTM model a leading indicator that reshapes its state probability distribution before the cortical signature becomes unambiguous. The dual-path combined output, fast-path SVM alert followed by LSTM confirmation or retraction within 7 to 9 seconds, achieved 83.1% critical overload recall at 0.13 false positives per flight hour, a rate that 79% of the 24 test pilots rated as acceptable in the post-session survey, against 41% acceptability at 0.25 events per flight hour tested in a separate calibration block with the same participants.

The EICAS recall deficit of 31.4 percentage points relative to the dual-path system is architecturally determined. EICAS logic issues no alert until pilot control inputs deviate from expected parameters; across 87 observed critical overload events in the autopilot disconnect scenario, the mean interval between physiological overload onset and the first deviant control input was 22.4 seconds, and the EICAS-modeled system's mean alert latency from event onset reached 28.6 seconds. The fast-path SVM fired at a median of 7.3 seconds by detecting phasic EDA amplitude and RMSSD suppression, both physiologically upstream of any behavioral response, tracking acute autonomic arousal within 3 to 6 seconds of stimulus onset. The gap is the quantified cost of conditioning alert issuance on behavioral evidence that becomes available only after the cognitive failure the system is intended to prevent.

Across the same 87 critical overload events, the fast-path SVM classifier produced a median detection latency of 7.3 seconds (IQR 5.9 to 9.1), the primary LSTM classifier 14.8 seconds, and the EEG-only threshold classifier 19.2 seconds, the last figure consistent with theta power's requirement for spectral accumulation over multiple windows before reaching discriminative threshold under the preprocessing constraints applied identically to all systems. Table 1 reports the complete performance profile.

Table 1.

Classification performance and detection latency by system

System	Three-class weighted F1	Critical overload recall	Median detection latency (s)	False-positive rate (events/hr)
LSTM ensemble (EEG + HRV + EDA)	0.847	78.6%	14.8	0.08
Fast-path SVM (HRV + EDA only)	0.761	72.3%	7.3	0.11
EEG-only threshold classifier	0.693	61.4%	19.2	0.08
Rule-based EICAS-modeled system	N/A	47.2%	28.6	0.08
Dual-path combined output	0.851	83.1%	7.3	0.13

The 5-minute baseline calibration conducted during the straight-and-level cruise segment specified in the Experimental Setup reduced between-pilot classification variance by 34.7% relative to population-norm thresholds, measured as reduction in the standard deviation of per-pilot F1 scores (SD = 0.091 with individual calibration versus SD = 0.139 with population thresholds). Extending the calibration window beyond 5 minutes yielded diminishing returns: the 2-to-5-minute extension reduced per-pilot F1 SD from 0.118 to 0.091, a 22.9% reduction; the 5-to-10-minute extension reduced it only a further 4.4% (SD = 0.087). Calibration failed for 4 of 24 pilots (16.7%) with resting LF/HF ratios above 3.8, for whom the two-feature fallback achieved a weighted F1 of 0.794, a 6.3 percentage point cost that directly quantifies the HRV channel's discriminative contribution when calibration succeeds.

The graded intervention module reduced PDT error rate in the high-load go-around scenario from 4.8 to 2.1 errors per 10-minute segment, a 56.3% reduction produced by suppressing the 14 low-priority alert classes that generated 3.2 attention-capturing events per minute in the unmodified cockpit. The mechanism is attentional budget redistribution, not capacity expansion: the benefit is bounded by the assumption that no suppressed alert class coincides with a concurrent secondary failure, a condition enforced by scenario design here but uncontrolled in open-ended operations. Vibrotactile seat-pad alerting achieved 4-second acknowledgment in 91.4% of critical events (79 of 87), against 67.8% for auditory-only alerting tested in a separate between-subjects block of 12 pilots under the same critical load scenario with identical alert timing, a 23.6 percentage point advantage attributable to the somatosensory pathway's lower attentional gating requirements under cognitive saturation (Causse et al., 2016). For the 8 pilots reporting pre-existing reduced lower-body tactile sensitivity, seat-pad delivery achieved 4-second acknowledgment in only 62.5% of events (5 of 8), identifying peripheral delivery channel as the boundary condition requiring supplementation.

Discussion

The temporal cascade structure of the physiological signals explains the performance hierarchy in Table 1 more precisely than any account based on additional information from multiple modalities. Sympathetic arousal following a high-workload event reaches cardiac rhythm within 3 to 6 seconds, producing the LF/HF shift the fast-path SVM detects at a median of 7.3 seconds post-onset; cortical reorganization sufficient to elevate frontal theta power requires accumulation over multiple oscillatory cycles, yielding the EEG-only classifier's 19.2-second median latency under identical preprocessing constraints. The LSTM model's 14.8-second latency sits between these values because its 10-second input window averages across both the early autonomic signal and the later cortical signal, sacrificing latency for the specificity that produces the F1 advantage. The performance ceiling of the LSTM path is therefore set by physiology: no redesign of the model that preserves the 10-second window can reduce latency below the window duration, and reducing the window sacrifices the spectral accumulation that the theta-band index requires to discriminate overload from artifact. The dual-path design resolves this by accepting the latency floor on the high-specificity path and running the low-latency path in parallel, not by engineering around the physiological constraint.

Contrary to Parasuraman and Manzey (2010), who concluded that automation complacency cannot be overcome by training or instructions, pilots in the partial autopilot handoff condition maintained PDT error rates of 2.1 errors per 10-minute segment after authority restoration, no higher than their pre-critical-event baseline of 2.3 errors per segment. Parasuraman and Manzey's strongest effect sizes came from sessions exceeding 45 to 90 minutes of continuous high-reliability automated supervision under stable, low-variance task conditions; the present 47-minute sessions included four distinct load phases with abrupt transitions that structurally prevented the monotonous, reliability-driven attentional withdrawal that generates the complacency mechanism.

The 31.4 percentage point recall gap between the dual-path system and the EICAS-modeled comparator carries an implication the framing as an academic performance advantage understates: it quantifies the structural recall failure of alert logic currently certified and operating in commercial revenue service. The EICAS comparator used here was modeled on the architecture of deployed systems. At 47.2% critical overload event recall under the conditions tested, it missed more than half the events it was designed to catch because it cannot detect physiological state. Aricò et al. (2016) demonstrated passive BCI triggering in realistic ATC conditions nine years before the present study; the gap

between that research demonstration and deployed system capability is a certification and integration problem, and the 22.4-second mean interval between physiological overload onset and first deviant control input documented here provides the quantitative argument for why the certification timeline has operational consequences that compound across every flight hour the gap persists.

The calibration failure rate of 16.7% for pilots with resting LF/HF ratios above 3.8 is a subpopulation problem with a directional bias. Chronic stress, sleep debt, and cardiovascular risk factors, all documented at elevated prevalence in the commercial pilot population, are associated with elevated resting sympathetic tone, which is what the LF/HF ratio above 3.8 indicates. Calibration therefore fails preferentially for a subpopulation at higher baseline cognitive risk, inverting the safety benefit the system is designed to provide for its most vulnerable users.

The vibrotactile acknowledgment result contains a counter-intuitive implication: the sensory channel that performed worst for 8 of 24 pilots is the one that performed best overall, and the failure is peripheral rather than central. The 23.6 percentage point advantage of seat-pad vibrotactile over auditory-only alerting under critical load reflects attentional gating asymmetry: vibrotactile stimulation at 100 Hz for 300 milliseconds produces an involuntary orienting response through a somatosensory pathway with substantially lower central attentional gating requirements than auditory processing under resource saturation, as documented by Causse et al. (2016) for the inattentional deafness phenomenon in ATC.

The 56.3% PDT error rate reduction under graded interface simplification requires a precision qualifier the headline number obscures: the improvement is attentional budget redistribution, not capacity enhancement, and its validity boundary is the priority ordering of the 14 suppressed alert classes. Across the standardized scenarios tested here, that ordering held by design. In open-ended operations with stochastically generated compound failures, a suppressed low-priority alert class may become high-priority through coincidence with a concurrent secondary failure, a condition the present experimental design, which used standardized single-failure scenarios, cannot characterize. The 56.3% figure represents the upper bound of interface simplification's benefit under clean single-failure conditions; its operational floor under compound failure configurations is the parameter this framework most urgently needs from a follow-on study using stochastic failure injection.

Conclusion

Integrating per-pilot calibrated multimodal biosignal fusion with a dual-path classifier architecture and a hysteresis-governed authority transfer protocol makes it possible, within the A320 simulator bounds specified, to detect critical pilot cognitive overload at a median latency of 7.3 seconds, 21.3 seconds faster than the EICAS-modeled comparator under identical test conditions, while maintaining a false-positive rate of 0.13 events per flight hour that 79% of test pilots rated as acceptable, and to reduce secondary task error rates by 56.3% through graded interface simplification; none of these capabilities has been previously validated as an integrated system against named baselines in a controlled high-fidelity simulator study with individual calibration. Whether the null complacency finding at 47-minute session durations persists when the partial autopilot handoff condition is sustained across cruise segments exceeding 90 minutes, the operational envelope where Parasuraman and Manzey's (2010) reliability-induced vigilance decrement is most likely to emerge and where the present architecture would be most continuously active, is the specific unresolved question on which the framework's primary safety claim depends.

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О НОВОЙ НАУЧНОЙ МОДЕЛИ СУЩЕСТВОВАНИЯ МАТЕРИИ В ВИДЕ ВЕЩЕСТВА

Вышинский В.А.
доктор технических наук, ведущий научный сотрудник института кибернетики имени В.М. Глушкова НАН Украины. Киев
https //orcid.org/0009-0006-5354-8469

ABOUT A NEW SCIENTIFIC MODEL OF THE EXISTENCE OF MATTER IN THE FORM OF SUBSTANCE

Vyshinsky V.
Doctor of Technical Sciences,
Leading Researcher at the Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine, Kyiv, Academician Glushkov
https//orcid.org/0009-0006-5354-8469
DOI: 10.5281/zenodo.21364263

АННОТАЦИЯ

В этой работе исследуется проблема существования материи в окружающем пространстве. Предложен вариант ее разрешения, позволивший создать принципиально новую модель физического поля, на основе которой рассмотрен вариант формы существования в природе: массы тела, магнита и электрического заряда, и в конечном итоге элемента таблицы Менделеева. Предложенная модель наиболее правдоподобно отражает действительность

ABSTRACT

This paper examines the problem of the existence of matter in the surrounding space. A proposed solution allows for the creation of a fundamentally new model of the physical field, based on which various forms of existence in nature are considered: the mass of a body, a magnet, an electric charge, and ultimately, an element of the periodic table. The proposed model most plausibly reflects reality.

Ключевые слова: проблема, понятие, термины математика, базис исследований, знания, фундаментальна.

Keywords: problem, concept, mathematical terms, research basis, knowledge, fundamental.

В настоящей статье ее автор претендует на пересмотр фундаментальных основ физики, включая теорию гравитации, квантовую механику и строение атома. Предлагается принципиально новое представление материи в окружающем пространстве, которое в дальнейших исследованиях приводит к познанию природы более фундаментально чем это имеет место в современной физике. Оно в познании природы выводит на существование материи в невещественном виде, что позволяет обнаружить, несколько иное представление материи, позволяющее открыть принципиально новую закономерность в ее существовании, отличную от той, которая имеет место сегодня. В частности, речь идет о законе взаимодействия материальных тел в окружающей среде, которое в современной физике объясняется ложным действием гравитации. Такой подход в объяснениях указанного ошибочного явления уже давно замечен научной общественностью, и публикуется в открытых работах [1,2,3,4]. Одновременно с этим, разрабатываются варианты новых теорий, вместо, теории гравитации. Таким образом, еще раз подчеркнем, что в настоящей статье предлагается принципиально новое представление материи в окружающем пространстве.

Практика исследований в естествознании показала, что научный сотрудник полученную им новую научную информацию о природе принимает всерьез, только тогда, когда она не противоречит его мировоззрению. Самым неприятным в этом случае есть то, что далеко не любое мировоззрение, которым владеет ученый отображает действительность. Как правило, в качестве критерия этой правдоподобности выступают понятия, термины, используемые в базисе теоретических исследований, с помощью которых ученый пытается познать законы природы. То есть, ответить на вопросы (проблемы): “Почему материя в окружающей среде в этих законах так устроена?”. Отмеченные понятия, и термины у него возникают, в результате анализа его же органов чувств, что отображают существование материи в виде вещества. И в этом случае выскажем гипотезу, что материя в окружающей среде не всегда проявляется веществом, т.е. в традиционном для человека виде. Иными словами, может находится она и в таком виде, который человеческие органы чувств, либо, вообще ее не “видят”, либо “видят”, только частично, и это не позволяет им определить истинное состояние природы.

Ярким примером ошибочной оценки окружающей среды является мировоззрение, основанное на известном законе Ньютона о всемирном тяготении. Напомним, в данном случае утверждается, что планеты вращаются вокруг Солнца под влиянием отмеченного выше закона Ньютона. То есть, именно солнечная гравитация и гравитация планет являются источником их движения по замкнутой кривой вокруг Солнца. В тоже время давно доказано, что сила тяготения гравитационного поля подчиняется экспоненте, т.е. математической функции, в которой гравитационное взаимодействие следует

закону обратных квадратов. Искусственный интеллект, отражающий знания большинства современных физиков, видит большую разницу между экспонентой и законом обычных обратных квадратов, забывая при этом, что определяющим явлением в обеих случаях играет математическая функция, в которой в знаменателе присутствует квадрат расстояния между источниками исследуемой гравитации. Иными словами, в математической модели закона обратных квадратов имеет место та же зависимость, что и в экспоненциальной функции. Однако, с позиций современных физиков утверждается, что экспоненциальное убывание, характерно лишь, для сильного взаимодействия (потенциал Юкавы), но не для дальнодействующей гравитации. Это утверждение современных физиков является глубоким заблуждением. Оно противоречит тому, что на дальнедействующем расстоянии, рассматриваемый закон обратных квадратов, сводит действие гравитации, вообще, к нулю, и это легко доказывается математически. Кроме того, возникает естественный вопрос, что из себя представляет дальнедействующая гравитация, на которой останавливаются современные физики. Если при этом, используется терминология из квантовой физики, которая предполагает существование мнимых дальнедействующих взаимодействий, то такие утверждения современных физиков не имеют под собой ничего научного. По существу, под этой фразой не сложно понимать не явление в природе, а междометие, относящееся к, чисто, бытовому употреблению, используемого в лексиконе человека

Искусственный интеллект в интернете своими, с позволения читателя “знаниями” [1,2,3,4], отражает грубейшие заблуждения. Ведь он утверждает, что гравитационное ускорение искусственного спутника на высоте 300 км. составляет около 8,9 м/с² (всего на 10% меньшее, чем на поверхности). И благодаря, именно, этому ускорению вес на спутнике уравновешивается с силой его притяжения Землей, которое, для этого тоже, должно быть уменьшена. на те же 10%. Именно в этом утверждении и присутствует ошибка. Ведь, на такой высоте над Землей под действием математической функции, описывающей закон обратных квадратов, т.е. гравитацию, как и любое энергетическое свойство материальной субстанции, должно быть уменьшено на, те же 10%. Но математика показывает, что это, далеко, не так. Таким образом, по мнению искусственного интеллекта благодаря именно этому ускорению и происходит вращение искусственных спутников. Тогда возникает естественный вопрос: “Каким способом при отсутствии, в этом случае, земной гравитации происходит вращение искусственных спутников. О каком свободном падении, на МКС, по мнению искусственного интеллекта речь идет, которое, согласно его утверждению, и обеспечивает движение вокруг Земли?” Ведь, по мнению указанного интеллекта состояние невесомости на МКС обусловлено свободным падением (орбитальным движением), а не отсутствием гравитации. Если бы гравитация была равна нулю, спутники улетели бы в открытый космос по прямой. По мнению автора настоящей статьи, причиной вращения спутников вокруг Земли выступает совершенно иной закон природы, который пока что находится вне внимания современной науки.

В настоящем изложении утверждается, что между малыми телами на Земле практически нет гравитационного притяжения. Виной тому есть большое, по величине земное притяжение, которое “перебивает” гравитационную связь между малыми телами. По мнению искусственного интеллекта, а значит и современных физиков, такое гравитационное взаимодействие существует между массами лабораторных масштабов и было экспериментально доказано Генри Кавендишем еще в 1798 году, и с тех пор многократно подтверждено с высокой точностью. В этом месте следует заметить, что если между указанными телами притяжение и существует, то его источником не является гравитация, а совершенно иное явление природы - новый закон природы, о котором уже упоминалось в настоящей статье.

Современные ученые, до сих пор, считают, что вращение Луны вокруг Земли, тоже, подчинено гравитационным силам этих двух космических тел. Однако вопрос: “Почему Луна постоянно повернута к Земле одной стороной?” не следует из действия указанных гравитационных сил. Ответ на этот вопрос тоже является большой загадкой.

Анализируя представление материи современной наукой, складывается впечатление, что все материальное вокруг нас возникло в какой-то момент существования мира. Например, в результате большого “взрыва”, и направляется к своему исчезновению с помощью аналогичного “взрыва” в той же материальной субстанции, но уже в иное время. Из этого следует, что материя существует в пространстве и во времени в конечных пределах. И тогда возникает естественный вопрос, а чем мир наполнен до ее появления, и что остается, когда материя в нем исчезает. Таким образом невольно напрашивается ответ, согласно которому в мире существует нечто нематериальное, отслеживающее - то появление материальной субстанции, то ее исчезновение. Приведенная выше мысль, весьма, роднится с гипотезой, согласно которой в мире существует что-то идеальное, отнесенное современной цивилизацией к религиозному началу.

В настоящей работе попытаемся, несколько по-иному, решить проблему материального существования мира. Для этого рассмотрим гипотезу, согласно которой, пространство и время в окружающей среде не имеет своих границ. Оно бесконечно, и не имеет свойств, согласно которым, оно то появляется в результате большого взрыва материальной субстанции, и то исчезает с помощью такого же взрыва, но уже в иное время. Кроме того, отмеченное свойство бесконечности пространства отражается в материальной субстанции, материализуя его.

Следует, также, заметить, что такое наполнение окружающей среды регистрируется той же материальной субстанцией, но только, когда она находится в, присущем только ей, живом виде. То есть,

материя, как бы сама себя видит своими органами чувств. Иными словами, в предлагаемых исследованиях рассмотрим гипотезу, более или менее, похожую на правду, согласно которой материя существует в разных своих видах [5,6]. То есть, не только в том, каким образом она представляется землянам в виде вещества. Причем, регистрация окружающей среды, при этом, для различных вариантов существования материи производится поразному. Еще раз подчеркнем, что традиционное "видение" у землян (нашей земной цивилизации), сводится к ощущению материи в виде вещества. А другие формы представления материи в окружающей среде имеют невещественное представление.

Бесконечность различных вариантов существования материи отслеживает то ее свойство, присущее пространству и времени, которое в рассматриваемом случае материализуется. Причем, тогда работает гипотеза, согласно которой на указанной бесконечности имеет место повторение вариантов ее существования с учетом новых условий. Нечто подобное имеет место на Земле, только, не новые цивилизации, а колонии живых организмов. Эта особенность природы позволяет человеческой цивилизации наблюдать за ними, и даже вмешиваться в их жизнь. Можно допустить, что на пути бесконечного представления материи в природе существует цивилизация, для которой человеческая менее развита, и, тогда с точки зрения этой неземной цивилизации, мы для нее можем быть подследственной. Это означает, что наша земная цивилизация, находясь под влиянием более развитой, меняет свои свойства, и таким образом, является управляемой, и познаваемой иной цивилизацией.

С другой стороны, эта новая цивилизация, как отмечалось ранее, ее материалистическая форма, может иметь возможность "чувствовать" окружающую среду по-своему. То есть, она воспринимает ее с помощью своего варианта вещества, который зиждется на свойственных ей органах чувств, и позволяет регистрировать, уже, иные законы природы. Попытаемся, хотя бы косвенно, обнаружить одну из таких цивилизаций. Для этого рассмотрим следующую модель человеческой цивилизации. Начнем с вариантов регистрации материальной среды, характерной землянам. Сегодня физики утверждают, что в природе имеют место четыре фундаментальных физических взаимодействия – гравитационная, электромагнитная, а также две ядерные силы одна сильная, а вторая слабая, и тоже ядерная [7]. Следуя современным авторитетным утверждениям, они описывают все известные материальные взаимодействия в природе на фундаментальном уровне. В тоже время можно заметить, что это, далеко, не так, и к фундаментальным взаимодействиям целесообразно отнести, лишь те из них, которые подтверждаются такими материальными свойствами, как явления в природе, т.е. законами природы. Тогда из приведенных четырех взаимодействий к фундаментальным можно отнести, только, гравитационное, поскольку оно обнаруживается, как явление в природе на Земле. Что касается трех - электромагнитного, сильного ядерного и слабого ядерного, то их отнести к фундаментальным таким способом в природе, очень, спорно. Ведь, каждое из них не есть явление в природе. Иными словами, их нельзя отнести к законам природы. Они отражают, чисто, теоретические изобретения человека, и только.

В качестве реального существования материи, которое взаимодействует и поддержано явлениями в природе, выступают следующие три взаимодействия. Условно назовем их: гравитационным, магнитным и электрическим. По нашим представлениям эта группа взаимодействий, в отличие от приведенных ранее четырех, имеет фундаментальную основу. Поскольку, для каждого из них есть возможность поставить в соответствие явление, которое можно отнести к законам природы. Действительно, гравитационное взаимодействие наблюдается в земельном притяжении произвольного вещества, находящейся на нашей планете. Магнитное имеет место между магнитами, а электрическое взаимодействие проявляется между двумя веществами предварительно обработанных трением.

Следует заметить, что эти взаимодействия, в нашем рассмотрении, т.е. в нашей модели, автономны. Иными словами, каждый из них проявляется, только, в рамках действия тех разновидностей вещества, которые обеспечивают, либо гравитацию, либо магнетизм, либо электрический заряд. То есть каждое взаимодействие имеет влияние над вещественными носителями: отдельно гравитации, отдельно магнетизма, отдельно электричества. Кроме того, отмеченное взаимодействие не проявляются перекрестно, а именно, силы гравитации не взаимодействуют с силами электрического заряда, и силами магнита, а силы магнита с силами электрического заряда. В этом месте, особо подчеркнем, что речь идет о полях, рассматриваемых, только, в настоящей статье. В дальнейшем изложении будет показана причина отсутствия перекрёстного взаимодействия каждого из отмеченных трех полей гравитационного магнитного и электрического.

Обратим внимание читателя на то, что научное познание природы требует два вида работ. Известно, что один из них приводит к объективным (истинным) знаниям. В этом месте изложения следует обратить внимание на то, что далеко не все работы, направленные на получение объективных знаний, добросовестно реализуются научными работниками. В частности, необходимо учитывать, что существуют исследования, используемые для развития метафизики. И такие действия научных работников приводят к результатам, весьма далеким, от правды природы.

В качестве второго вида работ выступают исследования, приводящие к субъективным знаниям, то есть к знаниям, которые нельзя отнести, окончательно, к правде о природе. Обычно, этот второй вид, направлен на познание того, почему в открытых законах природа так устроена. И он представляет собой теоретические исследования, основанные на абстрактных понятиях, и терминах, взятых из математики, либо изобретенных самим научным

сотрудником. И тогда их, как правило, следует отнести к субъективным знаниям, которые отображают, только, мировоззрение конкретного ученого. В познании закона существования трех, приведенных выше взаимодействий материи, воспользуемся вторым видом научных работ. Для этого, в отличие от традиционного подхода, основанного на абстрактных понятиях и терминах, взятых из математики, или миропонимания ученого, в его составляющем базисе исследований воспользуемся законами природы. Такой подход, с позиций автора настоящей статьи позволит получить результаты теоретических исследований более правдоподобными.

Таким образом, в предлагаемых теоретических исследованиях, которые приводят к реальным результатам, воспользуемся следующими законами. В качестве **первого** их них в исследовательский базис введем явление, которое отображает то, что материя во внешней среде находится в **движении**. Этот закон приводит материальную субстанцию **к интеграции, и де-интеграции** в фиксированном месте пространстве и времени, и его отнесем ко **второму закону.** Обнаружилось, что количественное изменение материи в этом случае приводит **к новому ее качеству** в вещественном представлении, и используемое нами в качестве **третьего закона в базисе.** Особо подчеркнем, что это явление перехода количественных изменений в новое качество имеет место не только при **интеграции**, но при **его де-интеграции**. В природе существует, также, **закон единства и борьбы двух противоположностей во время развития или деградации** существования материи, который обозначим **четвертым законом** в нашем базисе. Подчеркнем, что в создаваемом базисе теоретических исследований следует воспользоваться самим **законом развития и деградации** материальной субстанции, и его обозначим **номером пять**.

Приведенный выше базис законов, как и закон существования материи в виде вещества, определяется свойствами, которые обнаруживаются (регистрируются) вещественными ее представлениями (чувствами человека, и приборами их заменяющими). Этот базис может быть расширен и новыми законами, по мере использования его в наших исследованиях.

В настоящей статье используется теоретическая модель, описывающая околоземное пространство. Ее материальное представление составляет среду однородных материальных сгустков, находящихся в недвижимом состоянии, и которую обозначим эфиром. Указанная модель учитывает еще и то, что материя в ней в виде вещества находится в постоянном движении. И это ее состояние следует рассматривать, как развитие, которое “поддерживается” законами природы нашего базиса исследований. Напомним, среди них имеется закон единства и борьбы противоположностей. В таком развитии, кроме недвижимого эфира, имеются и движимые участки в нем. То есть, в предложенную модель, вместе с эфиром, введены дискретные сгустки материальной субстанции, которые движутся. Предположим, также, что через три взаимно перпендикулярные плоскости объема каждого такого сгустка, “течет” материальная субстанция, в виде обычной “жидкости”. Такую динамику субстанции идентифицируем с физическим полем, а интенсивность “течения” материальной субстанции с силовым его влиянием. При этом, знак этого влияния зависит от того поступает материальная субстанция в поток движения условной “жидкости”, либо ее покидает. Положительным значением силы поля в этом случае, будет вхождение субстанции в поток, а отрицательным – выход из него.

Таким способом во внешней среде вокруг материального сгустка генерируется три вида полей: гравитационное, магнитное и электрическое. В этом месте нашего изложения обратим внимание на то, что содержание понятия поля, рассматриваемого в настоящей статье, отличается от традиционного, принятого в обычной физической науке. Гравитационное поле, в этом случае, связано с прохождением материальной субстанции сквозь фронтальную плоскость сгустка. Силы этого поля действуют параллельно оси, что взаимно перпендикулярная с аналогичной осью, которая “проходит” сквозь профильную плоскость, и одновременно перпендикулярна к такой же оси, но уже, находящейся в горизонтальной плоскости сгустка. Исходя из этих условностей, положительный знак силы гравитационного поля определяет вхождение материальной субстанции в сгусток. Понятно, что с противоположной стороны он будет отрицательным. У профильной плоскости объема сгустка, таким же способом, генерируют силы магнитного поля, то есть перпендикулярно профильной плоскости. И в этом случае, с одной стороны, они имеют положительный знак, а с противоположной отрицательный. Что касается силовых линий электрического поля, то они формируются указанным движением материальной субстанции перпендикулярно горизонтальной плоскости. Одна сторона такого движения направлена на пополнение материальной субстанции сгустка - положительный знак силы электрического поля, а противоположная – выход из него, естественно, отрицательный знак.

Следует заметить, что в предложенной модели поля не существует отдельного источника с одним знаком, а другого с ему противоположным. То есть, любой источник поля, формирует вокруг себя, одновременно и положительные, и отрицательные значения силы каждого из трех полей. В этом месте отметим, что поля таким способом влияют на окружающую среду вокруг сгустка, притягивая материальную субстанцию недвижимого эфира, либо отесняя ее. Отмеченное поведение поля свяжем с таким понятием, как его силовое влияние на окружающую среду. Обратим внимание, также на то, что эти силы в меру их удаленности от центра сгустка, ослабевают. В тоже время количество условной материальной “жидкости”, которая “течет” в трех направлениях сгустка неодинакова, и как будет показано, зависит от вида поля, которое

при этом генерируется. Кроме того, еще раз подчеркнем, что силы, которые действуют на окружающую среду каждого в отдельности поля распределены по различным осям трехмерного пространства. Это означает, что силы гравитационного поля в таком пространстве находится вдоль оси перпендикулярной вертикальной плоскости, силы магнитного поля вдоль оси перпендикулярной профильной плоскости, а силы электрического поля вдоль оси перпендикулярной горизонтальной плоскости. То есть силы воздействия трех физических полей находятся по разными взаимно перпендикулярным направлениям, и это отражается на том, что указанные поля один от другого не зависят.

Таким образом, опираясь на предложенной в этой работе модели, рассмотрим каким образом материя превращается в вещество. Для этого остановимся на формировании нашей планеты, начиная с самых малых ее сгустков, и которое обеспечено природой в земных условиях. Не спешим с большими размерами внешнего пространства, которые выходят за пределы размеров Земли. Ведь вне нашей планеты могут находится, абсолютно, иные условия, и материя в них в виде вещества может оказаться в ином виде, и с другими свойствами. В окружении Земли сгустки материальной субстанции находятся на таком расстоянии между собой, на котором возникают силы взаимодействия между ними, только, под влиянием гравитационного поля. Для чего силы этого поля должны быть существенно большими, нежели аналогичные силы магнитного и электрического полей. Кроме того, напомним, что такое взаимодействие указанного поля возможно лишь в том случае, когда сгустки касаются одноименными плоскостями, перпендикулярно которым “течет” материальная субстанция. То есть, в данном случае они находятся один по отношению к другому фронтальными плоскостями таким образом, что в одном сгустке, перпендикулярно соответствующей плоскости, материальная субстанция, создавая гравитацию, покидает его, а в другом сгустке – входит в него. Силы гравитационного поля, которые в этом случае имеют отрицательное значение направлены в сторону общего тяготения, находящегося в центре гравитации Земли. Поскольку этот центр в земных условиях создается большим количеством материальных сгустков, то общая его сила тяжести очень большая. И тогда любая земная структура своим гравитационным полем ориентируется, только, к нему. В результате, все тела притягиваются к его центру, и “войти” еще одному источнику гравитации, в такой силовой процесс взаимодействия возможно лишь в том случае, если она в нем по своей величине сравнима с гравитацией, которая генерируется Землей. А такой возможности природа в земных условиях пока еще не предоставила. В результате любое тело существенно меньшее нашей планеты не в состоянии переориентировать свои гравитационные силы в сторону аналогичного тела, что находится рядом. И тогда гравитационное взаимодействие между телами на Земле, учитывая общее земное тяготение невозможно, что легко проверяется. Действительно, между вещественными телами на нашей планете гравитационное взаимодействие существенно ограничено, то есть тела не притягиваются одно к одному при помощи своих сил гравитации. Другими словами, их силовое взаимодействие вдоль гравитационной оси невозможно, поскольку оно в это время “занято” силой тяготения Земли. Вот, почему на нашей планете не работает известный закон всемирного гравитационного тяготения. То есть между малыми телами, по сравнению с Землей, тяготение на нашей планете отсутствует, и не потому, что оно слабое, и ни какими приборами его зафиксировать невозможно.

Рассмотрим, как в земных условиях возникают элементы, представленные в таблице Менделеева, то есть, форма материи в вещественном виде в наиболее приближенном к человеку окружению. Оказалось, что сгустки материальной субстанции, касаясь друг друга, и создают эти элементы. Так, вначале развития материи в виде вещества, на Земле возникают объединения двух сгустков. Удвоенный поток силовых линий, который возник в этом случае, с одной стороны своей фронтальной плоскости, имеет отрицательное значение гравитационного поля, то есть в нем гравитационные силы направлены на покидание материальной субстанции из сгустка. Как отмечалось, эти силы имеют свое направление в сторону центра Земли, то есть, они притягиваются силами общего земного тяготения. Что касается противоположной стороны сечения сгустка, то в нем материальная субстанция входит в него, и при этом, формирует уже положительное значение силы. Таким образом, ее направление действия совпадает с прямой, на которой находится гравитационная сила Земли, в результате чего, и состоится тяготение с ее помощью материальных сгустков окружающей среды. В этом случае увеличенный поток, который возникает, не изолирует окружающую материальную среду от земного тяготения, а наоборот, содействует удержанию вещества на нашей планете.

Напомним, в удвоенном сгустке, кроме гравитации, находятся еще и магнитное и электрическое поля. Магнитное поле в нем формируется с торца профильной плоскости каждой из двух составляющих входящих в удвоенный сгусток. Следует заметить, что количество материальной субстанции, которая, при этом, принимает участие в формировании магнетизма, существенно, меньшая той, что формирует гравитацию. В результате каждая из сил, которая притягивает и отталкивает магнитным полем, существенно, слабее, соответствующих сил гравитации, и их силового воздействия на соседние в пространстве сгустки. Однако, в самом удвоенном сгустке вход и выход силовых линий магнитного поля, каждой его половины, находятся на таком расстоянии друг от друга, что между ними возникают взаимодействия, которые приводят их к касанию. В результате, в каждом удвоенном сгустке формируется местный магнитный диполь. Их совокупность, до которой входят также иные

элементы земной массы, под действием своих магнитных сил формируют на Земле южный и северный магнитные полюса. Силовое влияние в этом случае магнитного поля осуществляется вдоль профильной оси нашей планеты.

Аналогичная ситуация складывается и с электрическим полем в удвоенном сгустке, касаясь его центра, но уже в горизонтальной плоскости. Количество материальной субстанции, которая “течет” перпендикулярно этой плоскости меньшая, нежели, то которое формирует магнитное поле в сгустке. То есть, в горизонтальных плоскостях сгустков возникают силы, которые притягивают и отталкивают от себя соседние сгустки в окружающем пространстве меньшие, по своей величине, нежели силы магнитного поля, и тем более гравитационного. Таким образом, ориентация удвоенных материальных сгустков вызывает ее силы электрического поля к взаимодействию, которые своей слабостью не замыкаются между собой аналогично силам магнитного поля. То есть, в этом случае не возникает электрический диполь. В результате источники электрических сил начинают под своим действием движение по кругу в горизонтальной плоскости вокруг центра сгустка.

То, что эти силы отображают свойства электрического поля, подтверждается простым экспериментом, который сводится к механическому трению двух тел. В процессе этого трения возникает разрыв удвоенных сгустков материальной субстанции, что останавливает вращение их источников электрического поля в горизонтальной плоскости. И тогда на поверхности не удвоенных сгустков, своей ориентацией движения материальной субстанции в них, появляются, один против одного, неудвоенные сгустки с противоположными зарядами. То есть, в этом случае возникают электрические заряды противоположных знаков. Следует, также, заметить, что в этом случае, одновременно, с разрывом силовых линий электрического поля, во время трения двоих тел, в удвоенном сгустке имеет место и разрыв магнитного диполя. Его составляющие, находясь перпендикулярно профильной плоскости сгустка, взаимодействуя между собой, влияют друг на друга. И таким образом, одновременно с источниками электрического поля, что появляются, в окружающем пространстве возникают магнитные поля с противоположными знаками. В результате их взаимодействие, совместно с электрическими зарядами, в пространстве появляется электромагнитная волна – фотон. Это в природе Земли человек ощущает своими органами чувств, а также приборами, в виде светового и звукового разряда указанных полей.

Следует также обратить внимание еще и на то, что удвоенный сгусток материальной субстанции в окружающей среде представляет собой отдельной материальной структурой, которая удерживается за счет сил притяжения гравитационного поля. И, как отмечалось, магнитные силовые линии в нем объединены в магнитный диполь, и, тем самым, принимают непосредственное участие в существовании удвоенного сгустка, как отдельного целого. Что касается сил электрического поля, то они, хотя и в меньшей мере, но тоже участвуют в целостности сгустка, и это имеет место в общей для двоих сгустков в горизонтальной плоскости. Появление таким способом удвоенного сгустка есть, не чем иным, как атомом наименьшего элемента таблицы Менделеева, т.е. водорода. В нем силы гравитационного поля отвечают за его массу, а оборот электрических зарядов вокруг центра удвоенного сгустка, отвечают за нахождение в атоме электрического поля. В этом месте следует обратить внимание на то, что это (электрическое) поле представлено не одним зарядом, который называется в современной физике электроном, а двумя, каждый из которых имеет противоположные знаки. Эти заряды в горизонтальной плоскости удвоенного сгустка, как отмечалось, сориентированы один против одного и их движение, в этом случае, вызывает движение вдоль окружности вокруг центра удвоенного сгустка – ядра атома.

Еще раз подчеркнем, что один элементарный носитель электрического поля в атоме, в отличие от современного понимания физики, имеет позитивный и отрицательный знаки. То есть, в нем имеет место вхождение в сгусток материальной субстанции и ее выход. Следует обратить внимание еще и на то, что электрическое поле в модели атома водорода играет очень важную роль в идентификации его, как отдельного элемента в таблице Менделеева. Также, силы электрических полей (их величины) обеспечивают прохождение химических реакций, отмеченного удвоенного сгустка, но уже с другим элементом таблицы Менделеева.

Итак, в настоящей статье предложена новая модель существования материи на Земле, которая основана на проявлении в ней принципиально новой формы существования гравитационного, магнитного и электрического полей. Такое понимание природы позволило построить новую модель атома, которая наиболее достоверно отображает действительность. Высказана гипотеза о том, что материя обладает способностью обнаруживать сама себя еще и отличным способом от того, как это осуществляется человеком на Земле. Иными словами, обнаружить существование материи в окружающем пространстве в невещественном виде, что невольно приводит к обнаружению новых законов природы. Исходя из полученных результатов в статье, возникает необходимость в переосмыслении многих явлений в природе. То есть, в исследовании новых моделей всего земного на основе предложенной модели материального существования. И для этого потребуются не одна статья, посвященная более глубокому познанию сути физического поля, вещественного представления элементов Таблицы Менделеева, раскрытию сущности электромагнитной волны (фотона), а также многих других физических явлений, которыми изобилует природа

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- Dudnik Oleg Arturovich, Doctor of Physical and Mathematical Sciences, Professor, Department of Physical and Mathematical management methods. (Chernivtsi, Ukraine)
- Konovalov Artem Nikolaevich, Doctor of Psychology, Professor, Chair of General Psychology and Pedagogy. (Minsk, Belarus)

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E-mail: info@european-science.org
Web: www.european-science.org